Desert Research Institute

Science Environment Solutions

Assessment of Drought Resiliency in Rural Northern Nevada

Wells, NV

Investigators: Greg Pohll, Rina Schumer, Susie Rybarski, Jackson Crews, Chris Pearson

Presented to: Nevada Division of Emergency Management

Date: July 31, 2016

Contents

Introduction 1
Objectives........ 1
Background 2
Groundwater Levels and Trends 2
Methods 2
    Modeling Methods........ 3
Diamond Valley (Eureka)........ 4
    Steady-State Model Design........ 4
    Transient Model Design 5
    Results 5
    Conclusions 5
Lovelock Valley (Lovelock) 6
    Steady-State Model Design........ 6
    Transient Model Design 7
    Results 7
    Conclusions 7
Winnemucca Segment and Grass Valley (Winnemucca) 8
    Steady-State Model Design........ 8
    Transient Model Design 9
    Results 9
    Conclusions 10
Walker Lake Valley / Whiskey Flat-Hawthorne Sub-Area (Hawthorne) 10
    Steady-State Model Design........ 11
    Transient Model Design 12
    Results 12
    Conclusions 12
Steptoe Valley (Ely) 12
    Steady-State Model Design........ 12
    Transient Model Design 13
    Results 13

Conclusions 13
Dixie Creek-Tenmile Creek Area (Spring Creek) 13
Steady-State Model Design 14
Transient Model Design 14
Results 15
Conclusions 15
Elko Segment (Elko) 15
Steady-State Model Design 16
Transient Model Design 16
Results 16
Conclusions 17
Upper Reese River Valley (Austin) 17
Steady-State Model Design 17
Transient Model Design 18
Results 18
Conclusions 18
Clovers Area (Battle Mountain) 18
Steady-State Model Design 18
Transient Model Design 19
Results 19
Conclusions 20
Conclusions 20
Recommendations 22
References 23
Tables 27
Figures 32

Introduction

Unusually severe to exceptional multi-year droughts are not an uncommon occurrence in Nevada. Although groundwater sources tend to be more resilient to short-term droughts than surface water sources, the intensity and length of the recent drought and the increase in population in recent decades have led to questions about the vulnerability of all of the state's municipal water systems. This includes those serving areas outside of urban centers. In 2013, the Nevada Drought Response Committee (DRC) held a strategic planning workshop during which the workgroup identified a goal of strengthening the resiliency of municipal water systems. The DRC recommended the development of public water supply vulnerability studies in the 2014 strategic plan.

The Nevada Division of Emergency Management (NDEM), in accordance with its mission of providing guidance to the state of Nevada and local jurisdictions on pre-disaster mitigation issues, desires to survey public water supply systems and domestic wells in rural northern Nevada to determine the vulnerability of those systems and sources to the effect of long-term drought. The NDEM also desires to develop guidelines to promote drought resiliency for municipal water systems and develop drought mitigation recommendations for rural water systems.

Most rural communities rely on groundwater to serve their customers. Generally, groundwater systems provide more resiliencies during drought periods because groundwater storage is typically much larger than surface water systems (e.g. reservoirs). Although the groundwater does allow small communities a certain amount of relief during short drought periods, groundwater levels can be depleted during long periods of drought. This study assesses the occurrence of drought and the potential effects on groundwater systems in northern rural Nevada.

This drought resiliency analysis focuses on small communities in northern Nevada. This includes communities north of highway 50 including Lovelock, Winnemucca, Battle Mountain, Carlin, Elko, Spring Creek, Wendover, Austin, Eureka, and Ely. This analysis also includes a general assessment of the potential impact drought may have on domestic wells. The domestic well analysis focuses on the expected shallow water table declines within each hydrographic basin in northern Nevada.

Objectives

This report presents the results a study designed to complete the following tasks:

1. Survey northern rural Nevada municipal/community water supply systems
2. Determine criteria for drought vulnerability of public water supply systems
3. Determine drought vulnerability for domestic wells
4. Develop municipal/community water system drought resiliency recommendations
5. Review and update the NV State Hazard Mitigation Plan's Drought Risk Assessment.

Background

Three or four major droughts occurred in the U.S. during the more than 100-year period for which records are available, not including the extreme and exceptional drought currently affecting Nevada and California. Two of the major droughts in that interval include the Dust Bowl of the 1930's and another drought during the 1950's. Both of those events persisted for a duration lasting between five and seven years, and both affected very large geographic areas (NOAA, 2008).

Medieval-era (1100-1300 CE) droughts were no more severe than modern droughts, but they persisted longer than any recent drought event, lasting 30-50 years (http://www.nasa.gov/press/2015/february/nasa-study-finds-carbon-emissions-could-dramatically-increase-risk-of-us). The likelihood of such persistent mega-droughts in the second half of this century may be exacerbated in the Southwest and Central Plains (Cook et al., 2015).

In designing a drought scenario for this study, a 15-year period of 50 percent recharge was selected as it represents a more severe and more persistent drought than has been recorded for the region, but still represents a fairly realistic scenario. There are several means by which drought is identified and its severity quantified, including the Palmer Drought Severity Index (Palmer, 1965), which is a comparison of current soil moisture to average soil moisture. For the present study, annual precipitation totals from each basin (wrcc.dri.edu) were compared to the mean total. In general, annual totals on the order of 50 percent of normal precipitation constitute some of the driest years on record.

Groundwater Levels and Trends

Observations of groundwater levels from some wells are available through the Nevada State Engineer's website. The change in water level between spring 2010 and spring 2015 was computed for each well that had complete records for that interval. The average change in water level between 2010 and 2015 in each basin is shown in Table 1. The table also includes the average rate of decline in feet-per-year, and the standard deviation, or uncertainty in the reported rate.

Methods

The study presented here was conducted primarily through numerical modeling. While eleven hydrographic basins were proposed for inclusion in this study, only nine were selected for modeling (Figure 1), based on a comparison of 2013 estimated groundwater use for each hydrographic basin relative to the perennial yield for that basin. Only basins showing annual use greater than 20% of the perennial yield were included in the modeling study (Table 2). However, it should be noted that although these basins were selected based on the state's estimation of perennial yield, these values were further researched and re-evaluated, and generally served only as a starting point for calibration of mountain block recharge and interbasin flow.

Modeling Methods

MODFLOW-NWT (Niswonger et al., 2011) was used to simulate the groundwater system within the selected hydrographic areas. MODFLOW is considered the industry standard and has been extensively tested and verified by numerous hydrogeologists. The model was developed within the Groundwater Modeling System (GMS) environment (version 10.0). GMS acts as a database for all of the hydrogeologic information and provides an easy to use pre- and post-processor to MODFLOW.

Model domains were defined by a 1-layer mesh of 0.386 mi^2 (1 km^2) grid cells fit to the shape of the hydrographic basin. Surface elevations were defined by a DEM, and grid cell thicknesses were determined by the difference between the surface elevation and a uniform bottom elevation. All models use the convertible layer option in MODFLOW, which allows for a variable saturated thickness as defined by the simulated water table position.

While the design of the individual basin models will be discussed later in this document, in general, models were developed to include zones of mountain block groundwater recharge, evapotranspiration (ET) over phreatophyte zones, rivers and streams, and interbasin flow where applicable. Hydraulic conductivities were determined by physical properties of the formations, analysis of aquifer test results where available, and use of the parameter estimation (PEST) function in GMS. With the exception of the municipal wells in some basins, the functionality and pumping rates of wells in these basins were not available. Therefore, each well with existing water rights as stated by the NDWR was assumed to be active and pumping at the full water right issued to that well, including those wells with only supplementary water rights.

For all modeled hydrographic basins, a minimum of three simulation periods were developed. First, a steady-state model was created to represent pre-development water levels. Steady state models were calibrated to observed water levels, such that the ratio of the mean absolute error to the total simulated head drop was less than 10%. These water levels were then used as the initial conditions for two sets of transient models – one set modeling normal mountain block recharge conditions, and one set modeling drought conditions, for which recharge was reduced by 50% from normal. Each transient simulation was run for 15 years. Any basin for which pumping rates were provided by the municipality for their municipal wells was modeled using both the full water right for municipal wells and the reported rates, a method described in more detail in the next paragraph. The basins for which pumping rates were provided for municipal wells are shown in bold in Table 2. Note that the 2013 estimated pumping rates shown in Table 2 are in many cases simply a percentage of the total water rights, and because their accuracy was unknown, these numbers were not used. Comparisons of water level difference plots between the transient and steady state simulations show the basin-wide drawdown effects of simple pumping versus the effects of lost recharge due to drought conditions. Plots of drawdown over time were also created for selected municipal wells to assess drought vulnerability for the public water supply and to better inform recommendations for drought resiliency.

Figure 2 delineates four different transient simulation scenarios. In Case-I, the mountain block receives the full recharge amount obtained from a basin report, and municipal wells are pumped at rates reported by the municipality. In Case-II the municipal well pumping rates are those reported by the municipality, but the recharge rate is reduced by half to simulate a severe drought. In Case-III municipal wells are pumped at their full water right allocation, while the mountains receive 100 percent of normal recharge. In Case-IV municipal wells are pumped at their full water right and the mountains only receive 50 percent recharge. Case-IV represents a scenario in which the availability of surface water is limited due to severe drought, prompting higher pumping rates from municipal wells to offset a shortfall from other sources. Case-III is included for comparison against Case-I so that additional drawdown due to increased pumping can be computed under normal recharge conditions. Similarly, comparison of drawdown after 15 years of simulation under Cases I and II or III and IV facilitate quantification of the impact of drought alone, in the absence of additional pumping. Comparison of Cases I and IV highlight regions of particular vulnerability under severe and persistent drought. In the absence of municipality-reported municipal well pumping rates for a given basin, only Cases III and IV were simulated. In all cases, wells in all other usage categories were pumped at their full water right duty, except for domestic wells, which were pumped at 0.7 AFA, in contrast to their associated water right of 2.0 AFA.

Diamond Valley (Eureka)

Steady-State Model Design

The steady state model for Diamond Valley (Figure 3) is constructed on a regular grid of 2119 3280 ft x 3280 ft (1 km x 1 km) cells. The top elevation of the grid was assigned using a DEM, and the bottom elevation was uniformly set at 2000 feet above mean sea level.

Recharge was applied to the mountains surrounding the valley at a uniform rate of 0.0003 ft/d or 21,000 AFA (Harrill & Lamke, 1968). The value 0.0003 ft/d was obtained by dividing the total daily recharge volume by the mountain block area.

Two specified flow arcs were used to simulate groundwater inflow from Devil's Gate (140 AFA) and Garden Valley (9000 AFA) (Eakin, 1962). These inter-basin groundwater inflows are represented as lines of injection wells at the western boundary of the model domain.

The maximum rate of evapotranspiration from the phreatophyte areas and playa were determined by dividing the annual discharge estimates for each zone by their respective areas. Approximately 0.00132 ft/d (25,000 AFA) is discharged by ET from phreatophytes and roughly 0.0003 ft/d (5,000 AFA) is discharged by ET from the playa (Eakin, 1962). The land surface elevation is used to model the elevation at which ET is maximized. The depth at which the ET rate goes to zero is set at 30 feet below land surface. The ET rate varies linearly between the maximum rate and zero as the hydraulic head varies from the land surface elevation to 30 feet below land surface.

Hydraulic conductivities of 1 ft/d and 5 ft/d were assigned to the mountain block and valley fill, respectively. These values were selected to reflect lower hydraulic conductivity in the mountains than in the valley, and to match model-simulated hydraulic head to pre-development water levels (Harrill & Lamke, 1968; Arteaga et al., 1995). The flow budget for the steady-state model is detailed in Table 3.

Transient Model Design

The effect of persistent drought and groundwater pumping on groundwater levels in Diamond Valley was modeled over a 15-year period. Four transient simulations were conducted. In the first, the full recharge rate was applied to the mountain block while municipal wells were pumped at rates reported by the municipality (Case-I). In the second scenario, recharge was reduced by 50 percent while the pumping rates remained unchanged (Case-II). In the third simulation, the mountain block received 100 percent recharge and the municipal wells were all pumped at their full water right duty (Case-III). In the fourth simulation, the mountain block received 50 percent of normal recharge while the municipal wells pumped at their full water right duty (Case-IV). In all four simulations, the starting hydraulic head is taken from the steady state model. The transient simulations were conducted with a specific storage of 0.0001 ft^{-1} and a specific yield value of 0.25 in the basin and 0.03 in the mountain block.

Results

Simulated groundwater elevations at the location of three municipal wells serving Diamond Valley are shown in Figures 4-7. At a scale that allows comparison with the elevation of the screened interval of the well, the 100 percent and 50 percent recharge cases are indistinguishable, differing by about 0.2 feet after 15 years. The average rate of water level decline in each case is approximately two feet per year – a rate that is consistent with the rate of decline obtained by averaging over all wells in the basin for which complete data are available for 2010-2015 (Table 1). The similarity between the water level response in the 100- and the 50-percent recharge cases indicates that the observed and the simulated groundwater drawdown is caused principally by groundwater pumping.

The difference in drawdown between the normal recharge scenario and the 50 percent recharge drought scenario (Figure 8) is about 0.2 ft after 15 years of pumping at the full water right duty at DV#1, DV#2, and the DV Airport well. Simulations were also carried using the reported pumping rates for DV#1, DV#2, and the DV Airport well averaged over the past five years. These lower pumping rates did not have an effect on simulated water levels, likely due the proximity of other wells – particularly irrigation wells – which are also pumping at high rates in the same grid cell or in adjacent grid cells.

The results of these simulations indicate the groundwater storage acts as a significant buffer against drought-induced reductions in groundwater elevation.

The largest difference between groundwater elevations between the 100 percent recharge scenario and the 50 percent recharge case in year-15 of the simulation occurs in the far-north and far-south ends of the Diamond Mountains, with a difference of less than 2 feet. At year-15 of the simulation, the difference in drawdown in the alluvial valley fill is 0.2 feet or less.

Conclusions

- Municipal supply wells DV#1, DV#2, and the DV Airport well are resilient to the impact of a 15-year severe drought.
- The most significant impact of drought occurs in the mountain block.
- The majority of the simulated drawdown in concentrated in the agricultural area, indicating that pumping for irrigation exerts a dominant influence on water level decline in Diamond Valley.

- No additional drawdown was observed at DV#1, DV#2, or the DV Airport well as a consequence of adjusting the pumping rates of those wells from the State-reported figures up to the full water right duty.
- Water level decline due to pumping presents a more significant threat to resilience than a 15-year severe drought.

Lovelock Valley (Lovelock)

Lovelock Valley, designated basin 73, and the Oreana sub-area, 73a, are located in west-central Nevada in Pershing County. The basin is bound by mountain ranges to the east and west. The Humboldt River enters the basin from the north and flows to the southwest, terminating in the Humboldt Sink (Figure 9). Under normal conditions the river is diverted to irrigate crops in the central valley, while in drought conditions surface water may not be available. While groundwater in upper Lovelock Valley and the Oreana sub-area is of generally good quality, groundwater in lower Lovelock Valley is largely of poor quality, and cannot be used as an interim replacement for lost surface water during drought conditions. The city of Lovelock obtains water from three municipal wells located in the Oreana sub-area, clustered closely together and likely pumping from the same aquifer (FARR West, 2015).

Steady-State Model Design

The Lovelock Valley model consists of 1931 3280 ft x 3280 ft (1 km x 1 km) grid cells. Cell elevations were determined by a DEM, and the base of the model was set at 2500 ft AMSL. Groundwater sources and sinks in Lovelock Valley include mountain block recharge, evapotranspiration, inter-basin flow, and well pumping – though pumping was not included in the steady-state model. The Humboldt River may also act as a head dependent source or sink of groundwater.

Recharge was modeled as several zones covering higher elevation areas in the mountains bounding the basin. Previous studies have estimated the total mountain block recharge in the basin during non-drought years to be approximately 3,200 AFA, with 2,000 AFA originating the in the Oreana sub-area (Everett and Rush, 1965). These values were used in the initial model design, then adjusted manually to improve steady-state model calibration. Studies have also estimated a 1000 AFA underflow from the Imlay basin to the north (Eakin, 1962), which was applied to this model as a specified flow along the northern boundary.

Evapotranspiration zones were applied to areas populated by phreatophytes, which fall primarily along the banks of the Humboldt River and the Humboldt sink. A maximum ET rate of 0.0004 ft/d was applied to these zones with an extinction depth of 20 ft below the surface after manual adjustment from rates given in Everett and Rush, 1965. However, the total volume of annual ET falls well below the number stated in this report. From Everett and Rush, 1965, “Most of the estimated evapotranspiration loss of 20,000 acre-feet per year is attributed to evaporation of canal and ditch water, transpiration from vegetation in or along the canals, and seepage losses from canals and ditches which support the large adjacent areas of phreatophytes.” Because these sources of ET are essentially surface water interactions, and because the intent of this model was to simulate groundwater responses, this large volume of ET was effectively 'short-circuited' by removing this source of water in order to simplify the model. The Humboldt River itself is in communication with the underlying aquifer, and was modeled as a head-dependent boundary using the River (RIV) Package in MODFLOW. The flow budget for the steady-state model is detailed in Table 4.

As little data was available to indicate the hydraulic conductivities of the basin materials, zonal values for the mountains and basin sediments were estimated based on rock and sediment types, then calibrated using the PEST function in GMS. The final hydraulic conductivities used in this model range from 0.0014 ft/d in the West Humboldt Range to 3 ft/d in the alluvium of the lower basin.

Transient Model Design

Three transient models were run – two with recharge rates set to 50% of those used in the steady-state model, and one with 100% of the steady-state recharge (Case-III), to assess the effect of lost mountain block recharge as opposed to simple pumping. Of the two models simulating 50% of normal recharge, one considered municipal wells pumping at their full water right (Case-IV), and the other used the average pumping rates for each well from 2012-2014 (Case-II), as reported by the Lovelock Meadows Water District. All other well types were allowed to pump at their full water right, with domestic wells pumping at a rate of 83.5 ft^3/d (0.7 AFA). Heads calculated by the steady-state simulation were used as the initial condition for the transient models, and all models were run to 15 years.

Results

All transient models show the development of several cones of depression surrounding pumping wells, with the greatest drawdown occurring at municipal wells 5, 7, and 8 during simulations pumping all wells at their full water right (Figure 10). Well 7 shows a drawdown of approximately 52 feet after 15 years at its full water right, or 15 feet after 15 years at the 2012-2014 average pumping rate (Figure 11). Wells 5 and 8 show a drawdown of 57 feet after 15 years at their full water right, or 18 feet after 15 years at the 2012-2014 average pumping rate (Figure 12). Note that because wells 5 and 8 fall within the same model grid cell, they must be analyzed as a single unit. These values differ somewhat from the observed drawdowns at these wells of 5 feet or less over the past 20 years, as a result of heterogeneities in the basin.

Following the municipal wells, the most severe declines in water level occur around several clusters of irrigation wells, with a maximum drawdown of approximately 50 feet in upper Lovelock Valley. While these declines in water level may affect nearby domestic wells, models indicate a maximum decline of approximately 10 feet after 15 years.

A comparison of drawdown resulting from transient models run at 50% and 100% of steady-state recharge does indicate a decline in groundwater levels in zones of mountain block recharge when under drought conditions (Figure 13). However, models showed no change in municipal well water levels as a result of changes in mountain block recharge during the simulated time period.

Conclusions

- Municipal supply wells are resilient to the impact of a 15-year severe drought.

- The most significant impact of drought occurs in the mountain block.
- Domestic wells located in or near the Humboldt Range in the Oreana sub-area may experience drawdown of up to 5 feet as a direct result of a 15-year severe drought.
- Drawdowns resulting from pumping municipal wells at their full water right are much greater than those resulting from pumping at the 2012-2014 average pumping rate.
- Drawdowns resulting from pumping of irrigation wells may impact nearby domestic wells.

Winnemucca Segment and Grass Valley (Winnemucca)

The Winnemucca Segment, referred to as basin 70, and Grass Valley, 71, are located in north-central Nevada in Humboldt and Pershing Counties. The basins are bound by hills and mountain ranges to the north, east, and west. The Humboldt River enters the Winnemucca Segment from the east and flows to the southwest, exiting into the adjoining Imlay basin. The city of Winnemucca is located in the Winnemucca Segment, but obtains water from five municipal wells located in both the Winnemucca Segment and the adjacent Grass Valley, as well as one mountain spring located in the Sonoma Range in Grass Valley (Figure 14). As such, this model includes both basins.

Steady-State Model Design

The Winnemucca Segment and Grass Valley model consists of 2472 3280 ft x 3280 ft (1 km x 1 km) grid cells. Cell elevations were determined by a DEM, and the base of the model was set at 3550 ft AMSL in the Winnemucca Segment and 0 ft AMSL in most of Grass Valley, with a linear decline in elevation at the mouth of Grass Valley. Groundwater sources and sinks in the two basins include mountain block recharge, evapotranspiration, inter-basin flow, springs, and well pumping – though pumping was not included in the steady-state model. The Humboldt River and mountain streams may also act as head dependent sources or sinks of groundwater.

Recharge was modeled as several zones covering higher elevation areas in the mountains bounding the basin. Previous studies have estimated the total mountain block recharge in the basins during non-drought years to be approximately 4,000 AFA in the Winnemucca Segment (Cohen et al, 1965; Nowlin, 1986) and 12,000 AFA in Grass Valley (Cohen, 1964). These values were used in the initial model design, then adjusted manually to improve steady-state model calibration. Studies have also estimated a 3,500 AFA underflow into the Winnemucca Segment from Paradise Valley to the north, and another 3,500 flows in from basins to the east (Cohen et al, 1965). Approximately 6,000 AFA is believed to enter the Winnemucca Segment as interbasin flow from Grass Valley (Cohen, 1964; Cohen et al, 1965), and the model was calibrated to this value.

Evapotranspiration zones were applied to areas populated by phreatophytes, which fall primarily along the banks of the Humboldt River and the central basin of Grass Valley. Maximum ET rates of 0.002 ft/d and 0.003 ft/d with extinction depths of 25 ft and 7 ft were applied to Grass Valley and the Winnemucca Segment, respectively. ET rates were calibrated to approach the model inputs of mountain block recharge and interbasin flow, less underflow exiting the model, while also allowing the Humboldt River to 'gain' along the Winnemucca Segment (Cohen et al, 1965). The Humboldt River itself is in communication with the underlying aquifer, and was modeled as a head-dependent boundary using the River (RIV) Package in MODFLOW. The flow budget for the steady-state model is detailed in Table 5.

In addition to the five municipal wells located in both basins, Winnemucca also obtains water from a mountain spring in the Sonoma Range in Grass Valley. This spring was modeled using the Drain (DRN) Package in MODFLOW, and the model was calibrated such that the outflow from the spring approached the total water rights on the spring.

As little data was available to indicate the hydraulic conductivities of the basin materials, zonal values for the mountains and basin sediments were estimated based on rock and sediment types, then calibrated using the PEST function in GMS. The final hydraulic conductivities used in this model range from 0.005 ft/d in the Sonoma Range to 15.5 ft/d in the mouth of Grass Valley.

Transient Model Design

Six transient models were run – four with recharge rates set to 50% of those used in the steady-state model (Cases II and IV), and two with 100% of the steady-state recharge (Cases I and III), to assess the effect of lost mountain block recharge as opposed to simple pumping. Of the four models simulating 50% of normal recharge, two simulations also considered the effect of a no-flow scenario in the Humboldt River. For these two scenarios, the conductance value of the river was set to zero, such that river water could not be transferred in or out of the aquifer. While recorded droughts have resulted in intermittent no-flow conditions in the Humboldt River within the Winnemucca Segment, this has never been observed for an extended period. These simulations therefore represent an extreme worst case scenario.

For each of these ‘sets’ of two models (two with 100% normal recharge, two with 50% normal recharge, and two with 50% normal recharge and a zero river conductance), one was run pumping municipal wells at their full water right, and the other used the average pumping rates for each well from 2012-2014, as reported by the City of Winnemucca. All other well types were allowed to pump at their full water right, with domestic wells pumping at a rate of 83.5 ft^3/d (0.7 AFA). Heads calculated by the steady-state simulation were used as the initial condition for the transient models, and all models were run to 15 years.

Results

All transient models show the development of several cones of depression surrounding pumping wells, with the greatest drawdown occurring in the Winnemucca Segment at a central point between several municipal and irrigation wells during simulations pumping all wells at their full water right (Figure 15). Wells 6 and 7 show a drawdown of approximately 117 feet after 15 years at their full water right, or 31 feet after 15 years at the 2012-2014 average pumping rates. For the scenarios with a zero river conductance, Wells 6 and 7 show a drawdown of approximately 131 feet after 15 years at their full water right, or 42 feet after 15 years at the 2012-2014 average pumping rates (Figure 16). Reduction of mountain block recharge did not have a significant effect on municipal well drawdown. Note that because wells 6 and 7 fall within the same model grid cell, they must be analyzed as a single unit.

Unlike the municipal wells, the mountain spring did show a significant reduction in flow as a direct result of drought conditions. Flow rates dropped from approximately 138 AFA in the steady state scenario to approximately 31 AFA after 15 years of severe drought (Figure 17). Municipal well pumping rates did not have a significant effect on spring flow.

A comparison of drawdown resulting from transient models run at 50% and 100% of steady-state recharge does indicate a decline in groundwater levels, particularly in zones of mountain block recharge, when under drought conditions (Figure 18). Domestic wells show a maximum drawdown of ~32 feet in the Sonoma Range as a direct result of severe drought conditions, though drawdown due to drought is less than a foot for most wells in the basins in scenarios with standard river conductance. However, scenarios modeling reduced mountain block recharge in combination with a zero river conductance showed some domestic wells located near the Humboldt River as having a drawdown of nearly 20 feet after 15 years (Figure 19).

Conclusions

- Municipal supply wells are moderately resilient to the impact of a 15-year severe drought.
- Loss of river flow has a more significant impact on well drawdown than does reduced mountain block recharge.
- Mountain spring flow may not be resilient to the impact of a 15-year severe drough.
- The most significant impact of drought occurs in the mountain block.
- Domestic wells located in or near the Sonoma Range in Grass Valley may experience drawdown of up to 32 feet as a direct result of a 15-year severe drought.
- The majority of the simulated drawdown is concentrated in the area of municipal and irrigation wells in both basins, indicating that pumping exerts a dominant influence on water level decline in Winnemucca and Grass Valley.
- Drawdowns resulting from pumping municipal wells at their full water right are much greater than those resulting from pumping at the 2012-2014 average pumping rate.
- Drawdowns resulting from pumping of irrigation wells may impact nearby domestic wells.
- Water level decline due to pumping presents a more significant threat to resilience than a 15-year severe drought.
- Any additional municipal supply wells should be located as far from existing pumping wells as possible to reduce combined drawdown.

Walker Lake Valley / Whiskey Flat-Hawthorne Sub-Area (Hawthorne)

The Whiskey Flat-Hawthorne sub-area of Walker Lake Valley, designated basin 110C, is located in west-central Nevada in Mineral County. The basin is bounded by mountain ranges to the east, south, and west, and by Walker Lake to the north (Figure 20). Walker Lake is a terminal lake fed by the Walker River. Diversions from this river for irrigation have resulted in a decreased inflow to the lake, and lake levels have been dropping steadily since the early 1900’s (Allander et al, 2014). While the lake itself does not fall within the Whiskey Flat-Hawthorne sub-area, the decline in lake levels has resulted in a corresponding decline in groundwater levels in this sub-area.

Steady-State Model Design

The Whiskey Flat-Hawthorne sub-area model consists of 1419 3280 ft x 3280 ft (1 km x 1 km) grid cells. Cell elevations were determined by a DEM, and the base of the model was set at 3000 ft AMSL. Groundwater sources and sinks in the Whiskey Flat-Hawthorne sub-area include mountain block recharge, evapotranspiration, and well pumping. Walker Lake also acts as a head dependent sink of groundwater.

Recharge was modeled as several zones covering higher elevation areas in the mountains bounding the basin. Previous studies have estimated the total mountain block recharge in the basin during non-drought years to be anywhere from 4750 AFA to 25000 AFA, though the high end is likely unreasonable (Everett and Rush, 1967; Allander et al, 2014). These values were used in the initial model design, then adjusted manually to improve steady-state model calibration.

Evapotranspiration zones were applied to areas populated by phreatophytes, which fall primarily along the shore of Walker Lake and a small zone near the center of the basin. A maximum ET rate of 0.0003 ft/d was applied to these zones with an extinction depth of 20 ft below the surface. Walker Lake is in communication with the aquifer adjacent to it, and the northern boundary along the lakeshore was therefore modeled as a specified head boundary.

As little data was available to indicate the hydraulic conductivities of the basin materials, zonal values for the mountains and basin sediments were estimated based on rock and sediment types, then calibrated using the PEST function in GMS. The final hydraulic conductivities used in this model range from 0.0098 ft/d in the Garfield Hills to 5.43 ft/d in the alluvium of the northern basin.

Because lake levels have been declining since the early 1900's, and because records of groundwater levels from that time period are extremely limited or non-existent, creation of a 'steady-state' model was done in two steps. First, a steady-state model was created to represent pre-development groundwater levels in the sub-area. Because lake level declines are the result of development, this model was only meant to represent groundwater levels before significant pumping had occurred, and was intended to represent the last year before a currently permitted municipal well was in use – 1968. The flow budget for this 'steady-state' model is detailed in Table 6.

Next, a transient model was created to bridge the gap between the 'steady state' water levels and the present (i.e., 1968-2015). To simulate declining lake levels, heads defined by the specified head boundary along the lakeshore were made to decline based on measurements of nearby monitoring wells from that time period. Municipal wells were allowed to pump at their full water right beginning in the year they were permitted, as actual pumping rates were not available for the wells in this basin. Groundwater levels predicted for 2015 by this transient simulation were then used as the initial condition for all transient drought simulations.

Transient Model Design

Two transient models were run – one with recharge rates set to 50% of those used in the steady-state model (Case-IV), and one with 100% of the steady-state recharge (Case-III), to assess the effect of lost mountain block recharge as opposed to simple pumping. Because actual municipal well pumping rates were not available for this basin, both transient simulations simulate municipal wells pumping at their full water right. All other well types were also allowed to pump at their full water right, with domestic wells pumping at a rate of 83.5 ft^3/d (0.7 AFA). Heads calculated by the 1968-2015 transient simulation described in the steady-state model design section were used as the initial condition for the transient drought models, and both models were run to 15 years.

The transient simulations were conducted with a specific storage of 0.0001 ft^{-1} and a specific yield value of 0.25 in the basin and 0.03 in the mountain block.

Results

Transient models indicate a maximum drawdown of approximately 13 feet in municipal wells in the Whiskey Flat area (south basin), and approximately 5 feet in the Hawthorne area (north basin) (Figure 21). A comparison of drawdown in municipal wells during drought and non-drought conditions revealed an increased drawdown during drought conditions of 0.009 feet in the Whiskey Flat area and 0.001 feet in the Hawthorne area (Figures 22 and 23).

A comparison of drawdown resulting from transient models run at 50% and 100% of steady-state recharge does indicate a decline in groundwater levels in zones of mountain block recharge when under drought conditions (Figure 24). However, models predict a drawdown of less than 3 feet over 15 years for nearby domestic wells.

Conclusions

- Municipal supply wells are resilient to the impact of a 15-year severe drought.
- The most significant impact of drought occurs in the mountain block.
- A 15-year severe drought does not pose a significant threat to domestic wells in this area.
- The majority of the simulated drawdown is concentrated in the area of municipal wells, indicating that municipal well pumping exerts a dominant influence on water level decline in the Whiskey Flat-Hawthorne area.
- Water level decline due to pumping presents a more significant threat to resilience than a 15-year severe drought.

Steptoe Valley (Ely)

Steady-State Model Design

The Steptoe Valley (Figure 25) steady state model was constructed on a regular grid of 5409 3280 ft x 3280 ft (1 km x 1 km) grid cells with a top elevation determined by a digital elevation model and a uniform bottom elevation of 4000 feet above mean sea level.

Recharge is applied to the mountain block surrounding the valley. The recharge rate of 0.00025 ft/d was obtained by dividing the perrenial yield for the basin - 70,000 AFA - (Eakin et al., 1967) by the area of the mountain block (Table 7).

The evapotranspiration rate for the phreatophyte zones was determined by dividing the phreatophyte area by the estimated ET discharge (70,000 AFA), yielding a value of 0.001 ft/d. This value was adjusted upward to 0.003 ft/d to match the 70,000 AFA ET discharge target. Creeks are modeled as drains that remove groundwater from the adjacent aquifer at a rate dependent on a user-prescribed conductance (32.8 ft^2/d) and the difference in elevation between the bed of the drain and the adjacent groundwater elevation.

Hydraulic conductivities of 15 ft/d and 20 ft/d were assigned to the mountain block and valley fill, respectively.

Transient Model Design

The transient model was implemented in two simulations. In the first, the recharge zone in the mountain block receives full recharge (Case-III). In the second transient simulation, the recharge rate is reduced by 50 percent (Case-IV). All wells are pumped at their full water right for a simulation period of 15 years. The transient simulations were conducted with a specific storage of 0.0001 ft^{-1} and a specific yield value of 0.25 in the basin and 0.03 in the mountain block.

Results

The highest simulated rate of water level decline was -3.5 ft/year over the 15- year simulation period at a municipal well on the west side of the valley (Figure 26). The largest observed rate of water level decline for Steptoe Valley is -4.0 ft/yr for 2010-2015. The largest difference in water level between the 100 percent and 50 percent recharge scenarios after 15 years of simulation was 1.6 feet. Grid cells that included municipal wells along the axis of the southern portion of the valley exhibited less than half a foot of water level decline relative to 100 percent recharge case. The difference in water level after 15 years under the 100 percent and 50 percent recharge scenarios is shown in Figure 27.

Conclusions

- Municipal water supply wells in the Steptoe Valley are resilient to a 15-year persistent drought.
- Wells completed in and near the mountain block are more susceptible to drought-induced water-level decline than wells located near the center of the valley.
- Most drought-induced water-level decline occurs at the southern end of the Schell Creek Range and in the Egan Range, near Ely.

Dixie Creek-Tenmile Creek Area (Spring Creek)

The Dixie Creek-Tenmile Creek Area, designated basin 48, is located in northeastern Nevada in Elko County. The basin is bound by the Pinon Range, the Elko Hills, and the Ruby Mountains to the west, north, and east, respectively. The South Fork Humboldt River enters the basin from the south and flows northwest out of the basin, ultimately converging with the Humboldt River just north of the basin. Within the basin, mountain runoff forms Dixie Creek, which flows southwest to northeast, and Tenmile Creek, flowing southeast to northwest – both ultimately joining the South Fork Humboldt River before flowing out of the basin. The majority of wells are located in the northeast and central parts of the basin, including all municipal wells supplying the town of Spring Creek (Figure 28).

Steady-State Model Design

The Dixie Creek-Tenmile Creek model consists of 1022 3280 ft x 3280 ft (1 km x 1 km) grid cells. Cell elevations were determined by a DEM, and the base of the model was set at 4000 ft AMSL. Groundwater sources and sinks in the Dixie Creek-Tenmile Creek area include mountain block recharge, evapotranspiration, inter-basin flow, and well pumping – though pumping was not included in the steady-state model. Dixie Creek, Tenmile Creek, and the South Fork Humboldt River also act as head dependent sources and sinks of groundwater.

Recharge was modeled as several zones covering higher elevation areas in the mountains bounding the basin. Previous studies have estimated the total groundwater recharge from runoff in the basin during non-drought years to be approximately 11,000 AFA (Rush and Everett, 1966). This value was used in the initial model design, then adjusted manually to improve steady-state model calibration. The same study also estimated a 600 AFA underflow from the South Fork Humboldt River subarea to the southeast, and a 400 AFA underflow from the Huntington Creek subarea to the southwest, which were applied to this model as specified fluxes along the southeast boundary in the area of the Huntington Creek and South Fork Humboldt River confluence.

Evapotranspiration zones were applied to areas populated by phreatophytes, which fall primarily along the banks of the Humboldt River and the Humboldt sink. A maximum ET rate of 0.0008 to 0.002 ft/d was applied to these zones with extinction depths ranging from 5 to 20 ft below the surface, dependent on plant type. The South Fork Humboldt River, Dixie Creek, and Tenmile Creek are in communication with the underlying aquifer, and were modeled as head-dependent boundaries using the River (RIV) Package in MODFLOW. A 9,000 AFA groundwater outflow was estimated in a previous study (Rush and Everett, 1966), and was modeled as a specified flux along the northwest boundary in the area of the South Fork Humboldt River outflow. The flow budget for the steady-state model is detailed in Table 8.

As little data was available to indicate the hydraulic conductivities of the basin materials, zonal values for the mountains and basin sediments were estimated based on rock and sediment types, then calibrated using the PEST function in GMS. The final hydraulic conductivities used in this model range from 0.001 ft/d in the Ruby Mountains to 10 ft/d in the alluvium of the area surrounding the confluence of Dixie Creek and Tenmile Creek with the South Fork Humboldt River.

Transient Model Design

Three transient models were run – two with recharge rates set to 50% of those used in the steady-state model, and one with 100% of the steady-state recharge (Case-III), to assess the effect of lost mountain block recharge as opposed to simple pumping. Of the two models simulating 50% of normal recharge, one considered municipal wells pumping at their full water right (Case-IV), and the other used the average pumping rates for each well from 2012-2014 (Case-II), as reported by the Spring Creek Utilities Company. All other well types were allowed to pump at their full water right, with domestic wells pumping at a rate of 83.5 ft^3/d (0.7 AFA). Heads calculated by the steady-state simulation were used as the initial condition for the transient models, and all models were run to 15 years. The transient simulations were conducted with a specific storage of 0.0001 ft^{-1} and a specific yield value of 0.25 in the basin and 0.03 in the mountain block.

Results

All transient models show the development of several cones of depression surrounding pumping wells, with the greatest drawdown occurring at municipal wells during simulations pumping all wells at their full water right (Figure 29). As the number of municipals in this basin makes individual analysis impractical, two representative wells were selected to show the effects of drawdown over time. Well 3 shows a drawdown of approximately 105 feet after 15 years at its full water right, or 13 feet after 15 years at the 2012-2014 average pumping rate (Figure 30). Well 10 shows a drawdown of 117 feet after 15 years at their full water right, or 16 feet after 15 years at the 2012-2014 average pumping rate (Figure 31).

A comparison of drawdown resulting from transient models run at 50% and 100% of steady-state recharge shows does indicate a decline in groundwater levels in zones of mountain block recharge when under drought conditions (Figure 32). Models showed no significant change in municipal well water levels as a result of changes in mountain block recharge during the simulated time period, however, domestic wells located in or near the mountain block may be affected.

Conclusions

- Municipal supply wells are resilient to the impact of a 15-year severe drought.
- The most significant impact of drought occurs in the mountain block.
- Domestic wells located in or near the Ruby Mountains or Pinon Range may be impacted by a 15-year severe drought.
- The majority of the simulated drawdown is concentrated in the area of municipal wells, indicating that municipal well pumping exerts a dominant influence on water level decline in the Dixie Creek-Tenmile Creek area.
- Water level decline due to pumping presents a more significant threat to resilience than a 15-year severe drought.

Elko Segment (Elko)

The Elko Segment of the Humboldt River Basin, designated basin 49, is located in northeastern Nevada in Elko County. The basin trends northeast to southwest, and is bound by the Adobe Range to the northwest and the Elko Hills to the southeast. The Humboldt River enters the basin from the northeast and flows to the southwest, roughly bisecting the basin. The city of Elko obtains water from 23 municipal wells, all located in the upstream half of the basin (Figure 33).

Steady-State Model Design

The Elko Segment model consists of 842 3280 ft x 3280 ft (1 km x 1 km) grid cells. Cell elevations were determined by a DEM, and the base of the model was set at 3000 ft AMSL. Groundwater sources and sinks in the Elko Segment include mountain block recharge, evapotranspiration, interbasin flow, and well pumping – though pumping was not included in the steady-state model. The Humboldt River also acts as a head dependent source and sink of groundwater.

Recharge was modeled as several zones covering higher elevation areas in the mountains bounding the basin. Previous studies have estimated the total mountain block recharge in the basin during non-drought years to be between 2,900 and 10,000 AFA (Maxey-Eakin, 1949; Epstein, 2004; Masbruch, 2011). An intermediate value was used in the initial model design, then adjusted manually to improve steady-state model calibration. Studies have also estimated a 9000 AFA underflow from the Dixie Creek-Tenmile Creek area to the southeast (Rush and Everett, 1966), and a 300 AFA underflow from Pine Valley to the south (Eakin, 1961), which were applied to this model as specified flow boundaries.

Evapotranspiration zones were applied to areas populated by phreatophytes, which fall primarily along the banks of the Humboldt River. A maximum ET rate of 0.002 ft/d was applied to these zones with an extinction depth of 20 ft below the surface. The Humboldt River itself is in communication with the underlying aquifer, and was modeled as a head-dependent boundary using the River (RIV) Package in MODFLOW. An estimated 100 AFA discharges to the adjoining Marys Creek area as interbasin flow, and was modeled as a specified flow boundary. The flow budget for the steady-state model is detailed in Table 9.

As little data was available to indicate the hydraulic conductivities of the basin materials, zonal values for the mountains and basin sediments were estimated based on rock and sediment types, then calibrated using the PEST function in GMS. The final hydraulic conductivities used in this model range from 0.05 ft/d in the Adobe Range to 12.5 ft/d in the alluvium of the central basin.

Transient Model Design

Three transient models were run – two with recharge rates set to 50% of those used in the steady-state model, and one with 100% of the steady-state recharge (Case-III), to assess the effect of lost mountain block recharge as opposed to simple pumping. Of the two models simulating 50% of normal recharge, one considered municipal wells pumping at their full water right (Case-IV), and the other used the average pumping rates for each well from 2012-2014 (Case-II), as reported by the City of Elko. All other well types were allowed to pump at their full water right, with domestic wells pumping at a rate of 83.5 ft^3/d (0.7 AFA). Heads calculated by the steady-state simulation were used as the initial condition for the transient models, and all models were run to 15 years. The transient simulations were conducted with a specific storage of 0.0001 ft^{-1} and a specific yield value of 0.25 in the basin and 0.03 in the mountain block.

Results

All transient models show the development of a single cone of depression surrounding the pumping wells in the northeastern half of the basin, with the greatest drawdown occurring near the city of Elko during simulations pumping all wells at their full water right (Figure 34). As the number of municipals in this basin makes individual analysis impractical, two representative wells were selected to show the effects of drawdown over time, as depicted in Figure 28. Well 18 shows a drawdown of approximately 99 feet after 15 years at its full water right, or 15 feet after 15 years at the 2012-2014 average pumping rate (Figure 35). Well 43 shows a drawdown of 72 feet after 15 years at its full water right, or 22 feet after 15 years at the 2012-2014 average pumping rate (Figure 36).

A comparison of drawdown resulting from transient models run at 50% and 100% of steady-state recharge does indicate a decline in groundwater levels in zones of mountain block recharge when under drought conditions. Models showed no significant change in municipal well water levels as a result of changes in mountain block recharge during the simulated time period, however, domestic wells located in or near the mountain block may experience up to 30 feet of drawdown as a direct result of a 15-year severe drought (Figure 37).

Conclusions

- Municipal supply wells are resilient to the impact of a 15-year severe drought.
- The most significant impact of drought occurs in the mountain block.
- Domestic wells located in or near the Adobe Range or Elko Hills may be impacted by a 15-year severe drought.
- The majority of the simulated drawdown is concentrated in the area of municipal wells, indicating that municipal well pumping exerts a dominant influence on water level decline in the Elko Segment.
- Water level decline due to pumping presents a more significant threat to resilience than a 15-year severe drought.

Upper Reese River Valley (Austin)

Steady-State Model Design

The Upper Reese River Valley (Figure 38) steady state model was constructed on a regular grid of 5279 3280 ft x 3280 ft (1 km x 1 km) grid cells with a top elevation determined by a digital elevation model and a uniform bottom elevation of 4000 feet above mean sea level.

Recharge is applied to the mountain block at a rate of 0.00017 ft/d, which was obtained by dividing the basin-wide recharge estimate - 37,000 AFA – (Eakin et al., 1965) by the area to which it is applied in the simulation.

Creeks are modeled as drains and the Reese River is modeled using the river package with a conductance of 0.01 ft^2/d.

The hydraulic conductivity of the valley is 10 ft/d in the simulation, with 5 ft/d on the phreatophyte area. The hydraulic conductivity of the mountain block is 1.0 ft/d. ET rates of 0.0025 ft/d and 0.0012 ft/d are applied to two phreatophyte zones. The flow budget for the steady state model is shown in Table 10.

Transient Model Design

The transient model was run with all wells pumping at their full water right duty, with the exception of domestic wells, which were pumped at 0.7 AFA. Two simulations were conducted to compare water levels under a full recharge scenario (Case-III) versus a 50 percent recharge drought simulation (Case-IV). The transient simulations were conducted with a specific storage of 0.0001 ft^{-1} and a specific yield value of 0.25 in the basin and 0.03 in the mountain block.

Results

The maximum simulated rate of water level decline at a municipal well was -0.5 ft/yr for the 15 year simulation period, though the maximum drawdown in the basin was greater than 20 ft after 15 years at an irrigation well (Figure 39). The average observed rate of decline was -0.9 ft/yr for 2010-2015. The largest difference in water level between the 100 percent and 50 percent recharge cases at a municipal well was 1.2 ft after 15 years of simulation (Figure 40). The largest difference in water level elevation across the entire model domain between the two recharge scenarios was 1.5 feet in the mountain block bounding the north end of the valley.

Conclusions

- Municipal supply wells in the Upper Reese River Valley are somewhat resilient to a 15-year severe drought, though less so than in other basins due to their proximity to the mountain block.
- The proximity of these wells to the mountain block increases their vulnerability.
- Agricultural pumping is the leading contributor to drawdown in the Upper Reese River Valley.
- The largest drawdown due to pumping is concentrated in the agricultural area southwest of Austin.
- Any new municipal supply wells should be located as close to the center of the valley as possible in increase drought resilience.

Clovers Area (Battle Mountain)

Steady-State Model Design

The Clovers Area (Figure 41) steady state model was constructed on a grid of 2029 3280 ft x 3280 ft (1 km x 1 km) cells with a top elevation provided by a DEM and a uniform bottom elevation of 2000 feet above mean sea level.

Creeks are modeled as drains, and the River package is invoked to model the Humboldt River; in each case the conductance value was 0.01 ft^2/d. River bed elevation was set at the intersection of the basin boundary and Humboldt River and at a third point in the interior of the basin. In each case, the river bed elevation was set to 15 feet below the land surface elevation, and the head stage of the river was set at five feet below the land surface elevation.

Recharge is delivered to four zones in the mountains surrounding the valley at a rate of 0.0002 ft/d. This recharge rate was obtained by evenly distributing the 10,000 AFA estimated mountain block recharge [R. Felling, personal communication] across four high-elevation regions at the margins of the basin. The balance of the recharge to the aquifer is provided by outflow from the Humboldt River.

Hydraulic conductivities values of 1 ft/d and 10 ft/d and were assigned to the mountain block and the center of the valley, respectively. The starting water levels are taken as the land surface elevation.

The ET rate (0.00023 ft/d) for the phreatophyte zone was computed by distributing 10,000 AFA over the phreatophyte area in HA 64. The flow budget for the steady state simulation is shown in Table 11.

Transient Model Design

The transient model was run with a specific storage of 0.0001 ft^{-1} and a specific yield of 0.03 in the mountains and 0.25 in the valley. All wells were pumped at their full water right duty for a 15-year simulation period. The water level in each grid cell was computed in each of the 15 years under two scenarios: one in which the mountain block received full recharge (Case-III) and another in which the recharge to the mountain block was reduced by 50 percent (Case-IV). Because a portion of the recharge to the aquifer is provided by river losses, two additional sub-scenarios of the 50-percent recharge case were simulated to examine the effect of a sudden drop in River stage that persists over the 15-year drought. In one sub-scenario the river stage falls by two feet (20 percent); and the other sub-scenario implements a five-foot (50 percent) drop in river stage.

Results

After 15 years of simulation the difference in water level between the 100 percent and 50 percent recharge scenarios (Figure 43) was less than or equal to 0.3 ft at the location of two municipal wells in Battle Mountain. The largest difference in drawdown between the 100-percent and 50-percent recharge scenarios is 1.9 feet, which occurs in the mountain block. The interior of the valley responds to a 15-year 50-percent recharge reduction with about 0.1 ft of additional drawdown relative to the 100 percent recharge case. That small difference is likely due to enhanced outflow from the river to the aquifer because the river stage was held constant in that simulation. The simulated rates of decline at these two municipal wells were -0.3 ft/yr and -0.6 ft/yr, consistent with the observed average rate of decline in the Clovers Area, which is about -0.6 ft/yr for 2010-2015.

For the 50-percent recharge case, implementation of a two-foot drop in river stage yields a maximum additional drawdown of 0.021 ft relative to the case in which the river stage is held fixed (Figure 44). This maximum additional drawdown occurs where the Humboldt River exits the west side of the valley. When the river stage drops five feet, the maximum additional drawdown, relative to the case in which the river stage is held fixed, is 0.052 ft, again occurring where the Humboldt River flows out of the west side of the valley (Figure 45).

Conclusions

- Drought-induced water-level decline was observed primarily in the mountains during the 15-year simulations.
- Groundwater pumping exerts a significantly stronger influence on groundwater elevation than does a 15-year severe drought.
- Drawdown at municipal supply wells near Battle Mountain and in the irrigated area north of the Humboldt River should be monitored to assess aquifer and well performance.
- The stage of the Humboldt River influences its interaction with aquifer, but river stage is difficult to predict on a heavily managed river, particularly under a prolonged drought scenario. However, the additional decline in water level imposed by dropping the river stage by 20 percent and by 50 percent is a full order of magnitude smaller than the effect of a 50 percent reduction in recharge, over 15 years of simulation.
- Any additional municipal supply wells should be located as far from existing pumping wells as possible to reduce combined drawdown.
- Any new wells should be drilled as far from the mountain block as possible.

Conclusions

In this study, the effects of persistent, severe drought on groundwater levels in nine hydrographic basins in Northern Nevada were assessed. This was carried out by running two or more transient groundwater flow simulations: one in which the mountains receive the full volume of normal recharge and municipal wells are pumped at the rate reported by the municipality (Case-I), or at the full water right for basins where municipal rates were not available (Case-III); the other simulation was run with the mountains receiving only 50 percent of normal recharge, with municipal wells running at their full water right allocation to simulate enhanced municipal demand during periods of limited surface water availability (Case-IV). Where data were available, a fourth simulation was carried using the 50 percent recharge value and municipal pumping rates reported by the municipality (Case-II). In each simulation, domestic wells were pumped at 0.7 AFA, which is smaller than the 2 AFA water right, but represents a more realistic value. All other wells were pumped at their full water right duty. The simulations were run over a period of 15 years, and the difference in water levels at year-15 was interpreted as the effect of the reduction in recharge in the mountains, as all other features of the simulations – besides recharge – were identical. Differences in water level between the two scenarios in year-15 were measured at the location of municipal wells, and the difference in water level was also mapped throughout the model domain to show region of greater and lesser sensitivity.

The differences in water levels between the 50 percent (drought) and 100 percent (normal) recharge scenarios in year-15 was generally small compared to the net decline in water level at a given location in the model. The largest difference in water level between the drought and normal recharge simulations in year-15 usually occurred in the mountains, where recharge is delivered to model. This result is not surprising because the reduction in recharge propagates through the model at a rate governed by the hydraulic diffusivity, which is the ratio of the hydraulic conductivity to the specific storage parameter (or the ratio of transmissivity to storativity). As a result regions near the recharge zone “feel” the effects of a sudden reduction in recharge much earlier than points farther from the recharge zone. A corollary to this observation is that wells located near the mountain block tend to be less resilient than wells near the center of the valley.

The reduction in recharge is not instantaneously communicated to all locations in the basin. As a result, the effect of the reduction in recharge is not evident at any of the municipal wells during the 15-year simulation period. With the values of hydraulic conductivity, K, and specific storage, S_s, used in the transient simulations, the time delay, t_{delay}, between the onset of a reduction in recharge and its expression as additional drawdown in a pumped well is approximated by:

$$t_{delay} = \frac{S_s}{K} d^2$$

where d is the shortest horizontal distance between the recharge zone and the well in question. A well located 10,000 feet from the recharge zone, for example, would respond to a sudden change in the recharge rate in the mountain block after approximately 5.5 years. The arrival of the drought-induced water-level change is not evident in Figures 3-5 because of the dominant influence of groundwater pumping.

In Diamond Valley, the most over-allocated basin according to the disparity between the total reported pumping and the perennial yield (interpreted here as the basin-wide annual recharge) water levels were reduced at most by 1.63 feet in the 50 percent recharge scenario after 15 years, relative to the full recharge case. This difference is interpreted as an effect of the drought. At municipal wells DV#1, DV#2, and the DV Airport well, the drought-induced difference in water levels were 0.2 ft, 0.3 ft, and 0.2 ft, respectively. Varying the pumping rate of these three wells caused no change in the simulated water level due to the proximity of other wells pumping at very high rates.

In the Steptoe Valley, the water level at the location of municipal wells in the 50 percent recharge case, relative to the 100 percent recharge case, differs by up to 1.3 feet after 15 years of simulation. Other municipal wells exhibited no difference in water level after the 15-year simulation period.

Similarly, the Reese River Valley simulations yielded a difference in water level at municipal wells ranging from 0.3-1.2 feet of additional drawdown under to the 50 percent recharge drought scenario.

For each of the modeled basins, the average observed rate of water-level decline for 2010-2015 (Table 1) was compared to the simulated rate of decline. These rates were generally comparable within the uncertainty of the reported figure indicating that the observed and simulated water-level decline can be attributed to groundwater pumping.

On balance, the influence of a persistent, severe 15-years drought on groundwater elevation in the eight modeled basins is relatively minimal, at least when compared to the rate of decline due to pumping.

Recommendations

The most significant impacts of the simulated drought occur first in the mountain, where groundwater is recharged. Wells in and near the mountain block tend to be affected earlier and more severely by a sudden reduction in recharge. For that reason, it recommended that new municipal wells be drilled as close to the center of the valley as possible.

Further, the largest simulated drawdown tends to occur where wells are closely spaced. This is due to the superposition of the drawdown response of each well on the adjacent aquifer. It observed that reducing pumping rates on municipal wells in Diamond Valley, for example, did not alter the drawdown at those wells because of the substantial pumping rates (or at least water right duties) of nearby wells. To avoid exacerbating water level decline at the location of existing municipal wells, it is recommended that new municipal wells be located as far from existing wells of all usage categories as is economically feasible.

Water level records are available at varying temporal resolution for some wells. Additional water level monitoring in more extant wells would provide valuable high-resolution feedback on aquifer and well performance.

While the effects of a simulated drought were small compared to the effect of pumping, the decline due to pumping alone is cause for concern, as it poses the greatest present threat to the resilience of municipal water resources.

References

Allander, K.K., R.G. Niswonger, and A.E. Jeton, 2014, Simulation of the lower Walker River Basin hydrologic system, west-central Nevada, using PRMS and MODFLOW models, U.S. Geological Survey Scientific Investigations Report 2014-5190, 93 p.

Arteaga, F. E., J. L. Smith, and J. R. Harrill, 1995, Irrigated croplands, estimated pumpage, and water-level changes in Diamond Valley, Eureka and Elko Counties, Nevada, through 1990, U.S. Geological Survey Open-File Report 95-107, prepared in cooperation with the Nevada Division of Water Resources.

Bredehoeft, J. D. Hydrogeology of the Lower Humboldt River Basin, Nevada, Water Resources Bulletin No. 21, Department of Conservation and Natural Resources, Carson City, Nevada, 48 p.

City of Carlin Water System, 2012, Water Conservation Plan

City of Wendover, 2010, Water Conservation Plan

City of Winnemucca, 2006, Water Conservation Plan

Cohen, P., 1964, A brief appraisal of the ground-water resources of the Grass Valley area, Humboldt and Pershing Counties, Nevada, Ground-Water Resources – Reconnaissance Series, Report 29, Department of Conservation and Natural Resources, Carson City, State of Nevada, 40 p.

Cohen, P. & Others, 1965, Water resources of the Humboldt River Valley near Winnemucca, Nevada, Geological Survey Water-Supply Paper 1795, 151 p.

Cook, B. I., T. R. Ault, and J. E. Smerdon, 2015, Unprecedented 21st century drought risk in the American Southwest and Central Plains, *Scientific Advances,* doi: 10.1126/sciadv.1400082

Eakin, T. E., 1961, Ground-water appraisal of Pine Valley, Eureka and Elko Counties, Nevada, Ground-Water Resources – Reconnaissance Report 2, Nevada Department of Conservation and Natural Resources, 41 p.

Eakin, T. E., 1962, Ground-water appraisal of Diamond Valley, Eureka and Elko Counties, Nevada, Ground-Water Resources – Reconnaissance Series, Report 6, Department of Conservation and Natural Resources, Carson City, State of Nevada 74 p.

Eakin, T. E., 1962, Ground-water appraisal of the Imlay Area, Humboldt River basin, Pershing County, Nevada, Ground-Water Resources – Reconnaissance Series, Report 5, Department of Conservation and Natural Resources, Carson City, State of Nevada 54 p.

Eakin, T. E., D. O. Moore, and D. E. Everett, 1965, Water resources appraisal of the Upper Reese River Valley, Lander and Nye Counties, Nevada, Water Resources-Reconnaissance Series Report 31, 63 p.

Eakin, T. E., R. D. Lamke, and D. E. Everett, 1966, Hydrologic reconnaissance of the Humboldt River Basin, Nevada, Water Resources Bulletin No. 32, State of Nevada Department of Conservation and Natural Resources, 98 p.

Eakin, T. E., J. L. Hughes, and D. O. Moore, 1967, Water-resources appraisal of Steptoe Valley, White Pine and Elko Counties, Nevada, Water Resources-Reconnaissance Series Report 42, State of Nevada Department of Conservation and Natural Resources, Carson City, 64 p.

Elko County Nevada, 2007, Water resource management plan

Epstein, B. J., 2004, Development and Uncertainty Analysis of Empirical Recharge Prediction Models for Nevada's Desert Basins, Hydrologic Sciences Program, University of Nevada, Reno, Master's Thesis.

Eureka County, Nevada Joint water conservation plan for Town of Eureka Water System Devil's Gate GID District #1 and District #2 Crescent Valley Town Water System

Everett, D. E. and F. E. Rush, 1965, Water resources appraisal of Lovelock Valley, Pershing County, Nevada, Water Resources-Reconnaissance Series Report 32, Department of Conservation and Natural Resources, Carson City, 51 p.

Everett, D. E. and F. E. Rush, 1967, A brief appraisal of the water resources of the Walker Lake Area, Mineral, Lyon, and Churchill Counties, Nevada, Water Resources-Reconnaissance Series Report 40, Department of Conservation and Natural Resources, Carson City.

FARR West, 2015, Water Conservation Plan, Lovelock Meadows Water District

Harill, J. R. and R. D. Lamke, 1968, Hydrologic response to irrigation pumping in Diamond Valley, Eureka and Elko Counties, Nevada, 1950-65, Water Resources Bulletin No. 35, State of Nevada Department of Conservation and Natural Resources, 114 p.

Hawthorne Army Depot, 2005, Water Conservation Plan

Hydrographic Area Summary, HA048, Dixie Creek – Tenmile Creek Area, Nevada Division of Water Resources

Hydrographic Area Summary, HA049, Elko Segment, Nevada Division of Water Resources

Hydrographic Area Summary, HA052, Marys Creek Area, Nevada Division of Water Resources

Hydrographic Area Summary, HA056, Upper Reese River Valley, Nevada Division of Water Resources

Hydrographic Area Summary, HA064, Clovers Area, Nevada Division of Water Resources

Hydrographic Area Summary, HA070, Winnemucca Segment, Nevada Division of Water Resources

Hydrographic Area Summary, HA073, Lovelock Valley – Oreana Subarea, Nevada Division of Water Resources

Hydrographic Area Summary, HA110C, Walker Lake Valley – Whiskey Flat, Nevada Division of Water Resources

Hydrographic Area Summary, HA153, Diamond Valley, Nevada Division of Water Resources

Hydrographic Area Summary, HA179, Steptoe Valley, Nevada Division of Water Resources

Hydrographic Area Summary, HA192, Dixie Creek – Great Salt Lake Desert, Nevada Division of Water Resources

Lander County Water District #1, 2007, Battle Mountain Water System, Water Conservation Plan

Masbruch, M. D., 2001, Appendix 4: Current Study Groundwater Recharge Estimates for Predevelopment Conditions and Ranges of Previously Reported Estimates of Groundwater Recharge for Each Hydrographic Area within the Great Basin Carbonate and Alluvial Aquifer System Study Area. In: Conceptual Model of the Great Basin Carbonate and Alluvial Aquifer System. V.M. Heilweil and L.E. Brookes (Eds.), U.S Geological Survey Scientific Investigations Report 2010-5193.

Maxey, G. B. and Eakin, T. E., 1949, Ground water in White River Valley, White Pine, Nye, and Lincoln Counties, Nevada. No. 8, State of Nevada Office of the State Engineer prepared in cooperation with the United State Department of the Interior Geological Survey, Carson City, Nevada.

Nevada State Engineer Water Level Database, http://water.nv.gov/data/waterlevel/

Niswonger, R. G., Panday, Sorab, and Ibaraki, Motomu, 2011, MODFLOW-NWT, A Newton formulation for MODFLOW-2005: U.S. Geological Survey Techniques and Methods 6-A37, 44 p.

Nowlin, J.O., 1986, A ground-water-quality monitoring program for Nevada, U.S. Geological Survey Open-File Report 78-768.

Palmer, W.C., Meteorological Drought (U.S. Weather Bureau, Washington, DC, 1965)

Robinson, T. W. and Fredericks, J. C., 1946, Ground Water in Lovelock Valley, Nevada, Water Resources Bulletin No. 2, Office of the State Engineer, State of Nevada, 24 p.

Rush, F. E. and Everett, D. E., 1966, Water resources appraisal of the Huntington Valley area, Elko and White Pine Counties, Nevada, Water Resources-Reconnaissance Series Report 35, Department of Conservation and Natural Resources, Carson City, 37 p.

Sinclair WC. 1963. Ground-Water Appraisal of the Long Valley-Massacre Lake Region, Washoe County, Nevada. Nevada Department of Conservation and Natural Resources. Groundwater Resources-Reconnaissance Report 15.

Spring Creek Utilities Co., 2012, Water Conservation Plan

Welch, A. H., Bright, D. J., and Knochenmus, L. A., eds., 2007, Water resources of the Basin and Range carbonate-rock aquifer system, White Pine County, Nevada, and adjacent areas in Nevada and Utah: U.S. Geological Survey Scientific Investigations Report 2007–5261, 96 p.

http://www.nasa.gov/press/2015/february/nasa-study-finds-carbon-emissions-could-dramatically-increase-risk-of-us

Tables

Table 1. Trends in groundwater elevation for the period 2010-2015.

Basin No.	Basin Name	Average Water Level Decline (ft/5 yrs)	Standard Deviation of rate (ft/5 yrs)	Maximum Decline (ft/5 yrs)	Average rate of decline (ft/yr)	Standard Deviation of Rate (ft/yr)	Number of wells in basin with records	No. of wells with complete 2010-2015 records
56	Upper Reese River Valley	4.7	2.6	10.9	0.9	0.5	33	26
64	Clovers Area	-3.0	8.2	8.0	-0.6	1.6	107	42
52	Mary's Creek Area	2.1	1.9	5.1	0.4	0.4	9	9
49	Elko Segment	-3.0	8.2	8.0	-0.6	1.6	24	17
179	Steptoe Valley	2.0	5.0	20.1	0.4	1.0	108	41
153	Diamond Valley	9.8	7.0	38.1	2.0	1.4	165	57
110C	Walker Lake Valley						0	0
73	Lovelock Valley	0.4	1.6	2.8	0.1	0.3	17	4
48	Dixie Creek - Tenmile Creek Area	1.6	1.3	3.2	0.3	0.3	48	11
192	Great Salt Lake Desert						0	0
70	Winnemucca Segment	4.3	3.4	11.2	0.9	0.7	23	13

Table 2. Groundwater pumping by basin, *from* Nevada Statewide Assessment of Groundwater Pumpage, 2013. Volumes in acre-feet.

Hydrographic Area	Basin / Municipality	MM	IND	ENV	IRR	STK	MUN	QM	DOM	REC	COM	OTH	TOTAL	PY	% of PY
153	**Diamond Valley / Eureka**	**1,421**	**0**	**0**	**100,893**	**857**	**1,657**	**245**	**96**	**0**	**5**	**0**	**105,173**	**30,000**	**350.6**
73 & 73A	**Lovelock Valley / Lovelock**	**1,060**	**0**	**0**	**5,816**	**61**	**1,327**	**109**	**125**	**5**	**309**	**0**	**8,811**	**4,200**	**209.8**
70 & 71	**Winnemucca Segment & Grass Valley / Winnemucca**	**85**	**1,387**	**14**	**46,414**	**146**	**3,900**	**864**	**1,366**	**414**	**124**	**49**	**54,763**	**30,000**	**182.5**
110C	Walker Lake Valley / Hawthorne	0	72	0	1,676	6	5,798	2	19	0	41	152	7,766	5,000	155.3
179	Steptoe Valley / Ely	29,137	69	0	30,761	260	3,616	1,360	437	41	20	0	65,701	70,000	93.9
48	**Dixie Creek-Tenmile Creek Area /Spring Creek**	**389**	**10**	**0**	**289**	**204**	**3,068**	**5**	**515**	**5,637**	**68**	**12**	**10,197**	**13,000**	**78.4**
49	**Elko Segment / Elko**	**1**	**26**	**41**	**218**	**177**	**7,214**	**508**	**1,117**	**45**	**693**	**0**	**10,038**	**13,000***	**77.2**
56	Upper Reese River Valley / Austin	0	0	0	18,819	64	44	499	64	0	0	0	19,490	37,000	52.7
64	Clovers Area / Battle Mountain	676	3,176	0	10,804	220	113	25	159	528	0	0	15,701	72,000	21.8
52	Marys Creek Area / Carlin	0	0	724	117	13	262	0	16	0	0	0	1,132	13,000*	8.7
192	Great Salt Lake Desert / Wendover	0	0	0	0	6	0	0	3	0	0	0	9	5,000	0.2

MM = Mining and Milling, IND = Industrial and Construction, ENV = Environmental, IRR = Irrigation, STK = Stock, MUN = Municipal, QM = Quasi-municipal, DOM = Domestic, REC = Recreation and Wildlife, COM = Commercial, OTH = Other, PY = Perennial Yield

Basins with municipal pumping rates available are listed in bold

*Combined value for hydrographic areas 49 and 52

Table 3. Flow budget for Diamond Valley (Eureka) steady-state simulation.

	Rate (ft^3/d)	Rate (AFA)
Sources		
Mountain Block Recharge	2685301	22501
Interbasin Flow	1090790	9140
Sinks		
Evapotranspiration	-3776090	-31641

Summary	**Sources - Sinks (ft^3/d)**	**Percent Difference**
	0.095	2.5E-06

Table 4. Flow budget for Lovelock Valley (Lovelock) steady-state simulation.

	Rate (ft^3/d)	Rate (AFA)
Sources		
Mountain Block Recharge	339203	2842
Interbasin Flow	117430	984
River Seepage	12342	103
Sinks		
Evapotranspiration	-414464	-3473
River Seepage	-54511	-457

Summary	**Sources-Sinks (ft^3/d)**	**Percent Difference**
	0.198	4.2E-05

Table 5. Flow budget for Winnemucca Segment/Grass Valley (Winnemucca) steady-state simulation.

	Rate (ft^3/d)	Rate (AFA)
Sources		
Mountain Block Recharge	1938839	16246
Interbasin Flow	835397	7000
River Seepage	593591	4974
Sinks		
Evapotranspiration	-2218769	-18592
River Seepage	-774458	-6489
Drains (Spring)	-16575	-139
Interbasin Flow	-358027	-3000

Summary	**Sources-Sinks (ft^3/d)**	**Percent Difference**
	-2.80	8.3E-05

Table 6. Flow budget for the Whiskey Flat-Hawthorne (Hawthorne) steady-state simulation.

	Rate (ft^3/d)	Rate (AFA)
Sources		
Mountain Block Recharge	985241	8256
Sinks		
Evapotranspiration	-102394	-858
Specified Head (Walker Lake)	-882847	-7398

Summary	**Sources-Sinks (ft^3/d)**	**Percent Difference**
	0.017	1.7e-06

Table 7. Flow budget for Steptoe Valley (Ely) steady-state simulation.

	Rate (ft^3/d)	Rate (AFA)
Sources		
Mountain Block Recharge	9171598	76851
Sinks		
Evapotranspiration	-9171601	-76851

Summary	**Sources - Sinks (ft^3/d)**	**Percent Difference**
	-3.39	-3.7E-05

Table 8. Flow budget for the Dixie Creek-Tenmile Creek (Spring Creek) steady-state simulation.

	Rate (ft^3/d)	Rate (AFA)
Sources		
Mountain Block Recharge	1210043	10139
Interbasin Flow	119342	1000
River Seepage	818686	6860
Sinks		
Evapotranspiration	-476976	-3997
Interbasin Flow	-1074082	-9000
River Seepage	-597007	-5002

Summary	**Sources-Sinks (ft^3/d)**	**Percent Difference**
	5.79	2.7E-04

Table 9. Flow budget for the Elko Segment (Elko) steady-state simulation.

	Rate (ft^3/d)	Rate (AFA)
Sources		
Mountain Block Recharge	471709	3953
Interbasin Flow	1109890	9300
River Seepage	1595623	13370
Sinks		
Evapotranspiration	-1487313	-12463
Interbasin Flow	-11934	-100
River Seepage	-1677990	-14060

Summary	**Sources-Sinks (ft^3/d)**	**Percent Difference**
	-14.93	-4.7E-04

Table 10. Flow budget for the Upper Reese River Valley (Austin) steady-state simulation.

	Rate (ft^3/d)	Rate (AFA)
Sources		
Mountain Block Recharge	4816977	40363
Sinks		
Evapotranspiration	-3468342	-29062
Drainage to creeks and river	-1348660	-11301

Summary	**Sources - Sinks (ft^3/d)**	**Percent Difference**
	-25.53	-5.3E-04

Table 11. Flow budget for the Clovers Area (Battle Mountain) steady-state simulation.

	Rate (ft^3/d)	Rate (AFA)
Sources		
Mountain Block Recharge	1127877	9451
River Seepage	3450	29
Sinks		
Evapotranspiration	-1075308	-9010
Drainage to creeks	-5159	-43
River Seepage	-50857	-426

Summary	**Sources - Sinks (ft^3/d)**	**Percent Difference**
	2.70	2.3E-04

Figures

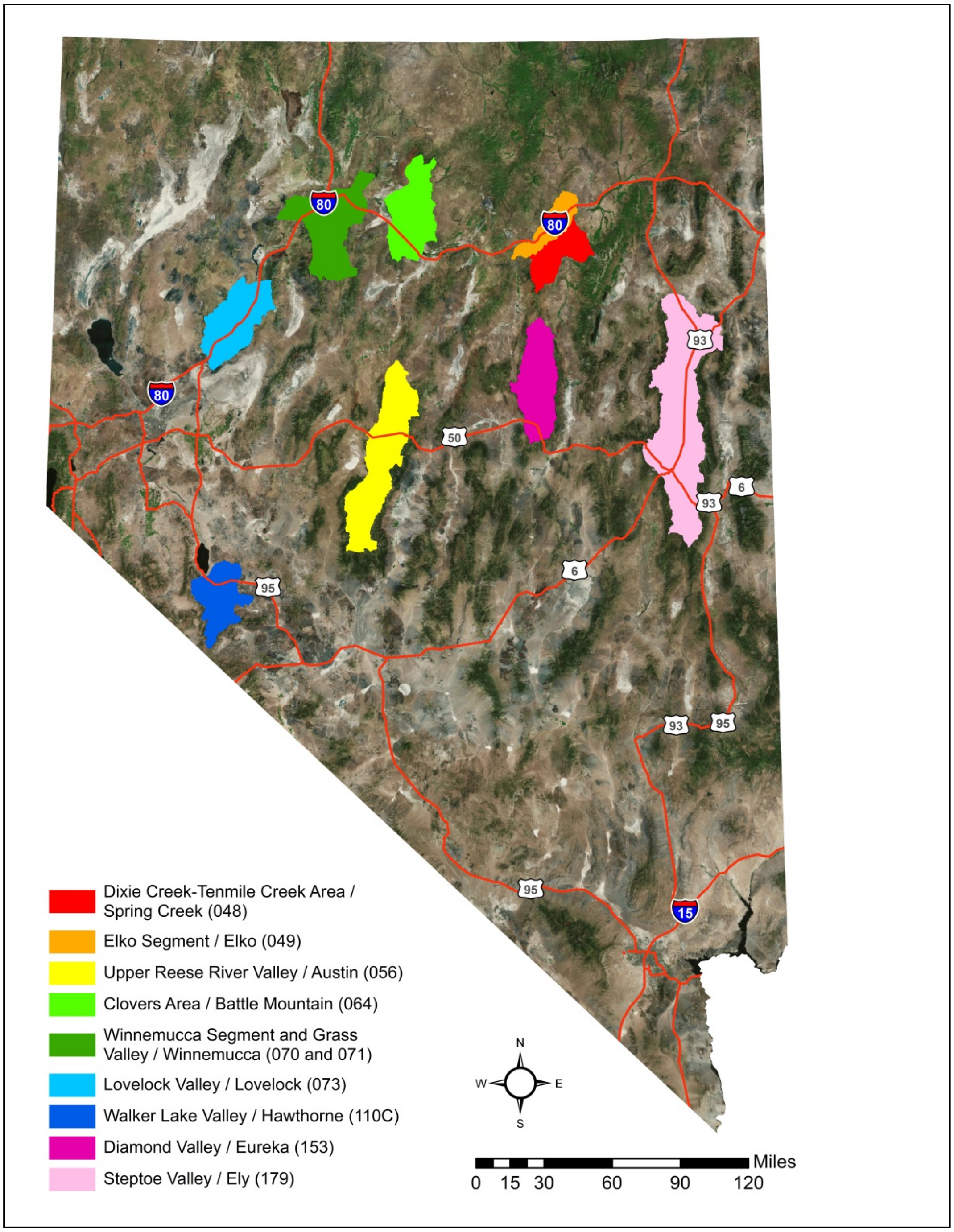

Figure 1. Hydrographic areas modeled for the study presented in this report

		Percent of Normal Recharge	
		100	50
Municipal Well Pumping Rates	Reported rates	Case-I	Case-II
	Full Water Right	Case-III	Case-IV

Figure 2. Transient simulation scenarios

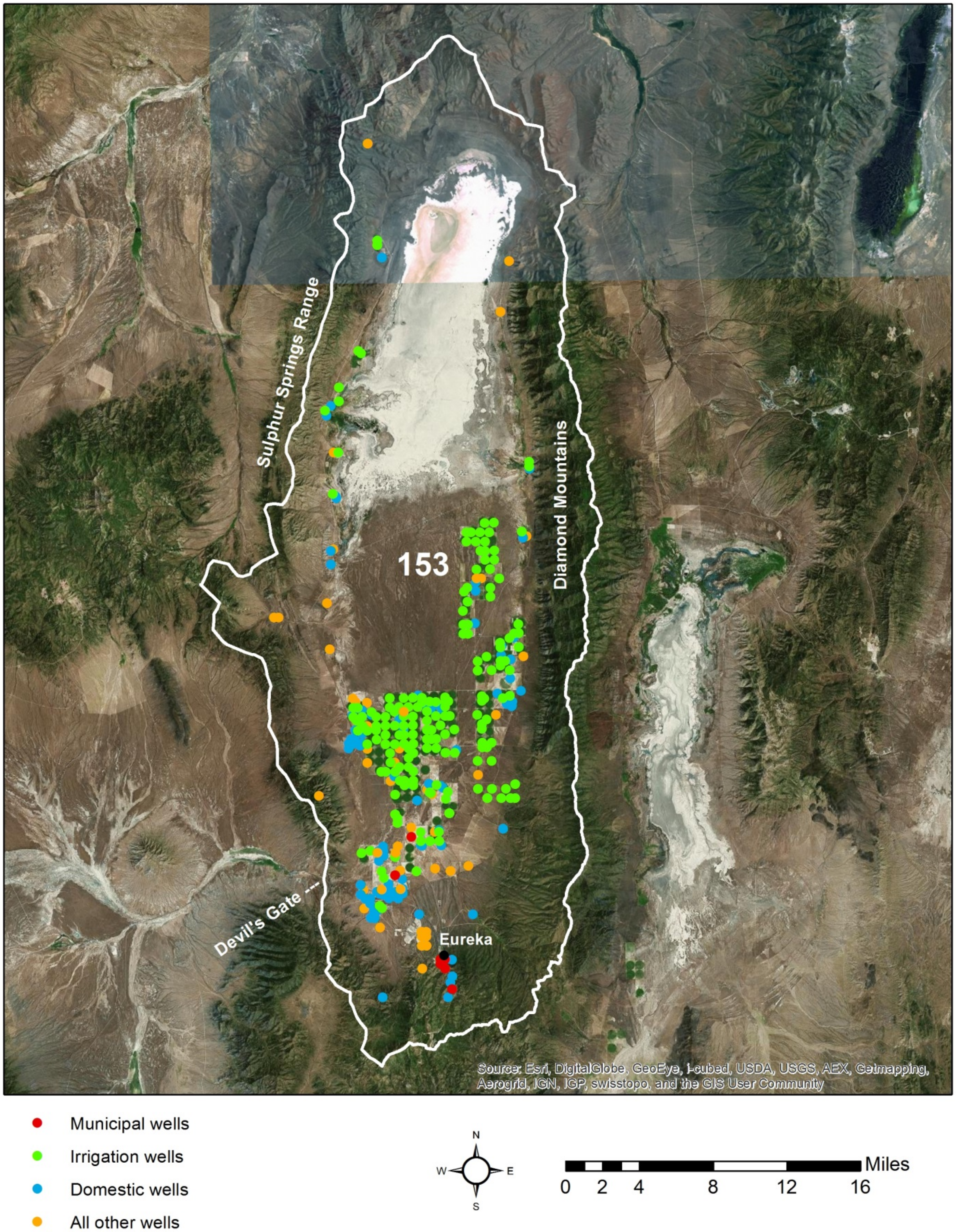

Figure 3. Diamond Valley (153), and locations of wells used in transient simulations.

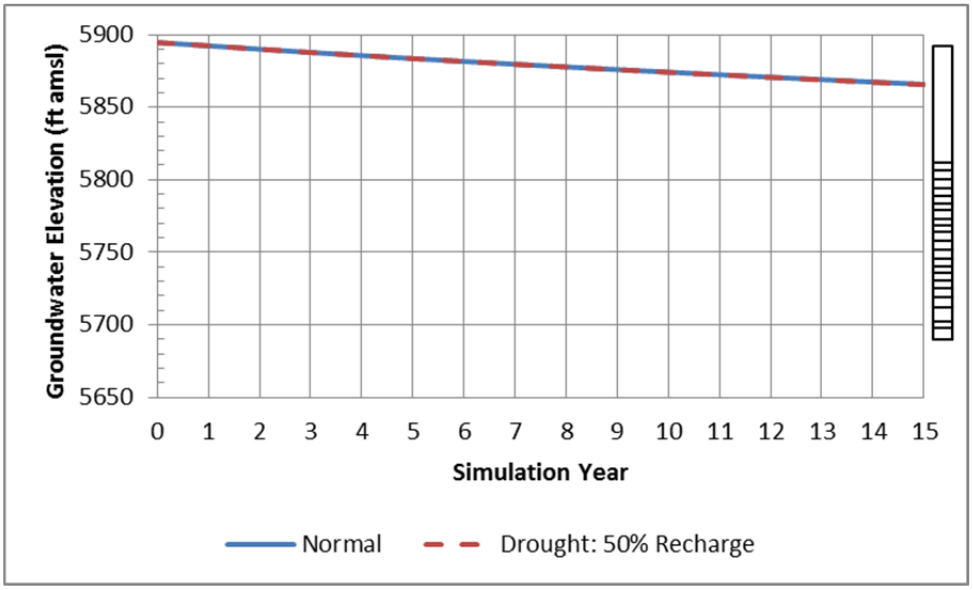

Figure 4. Plot of groundwater elevation at well DV#1 as a function of time under normal (100 percent) recharge conditions and under drought conditions represented by a 50 percent recharge scenario. The elevation of the screened interval of the well is shown on the right.

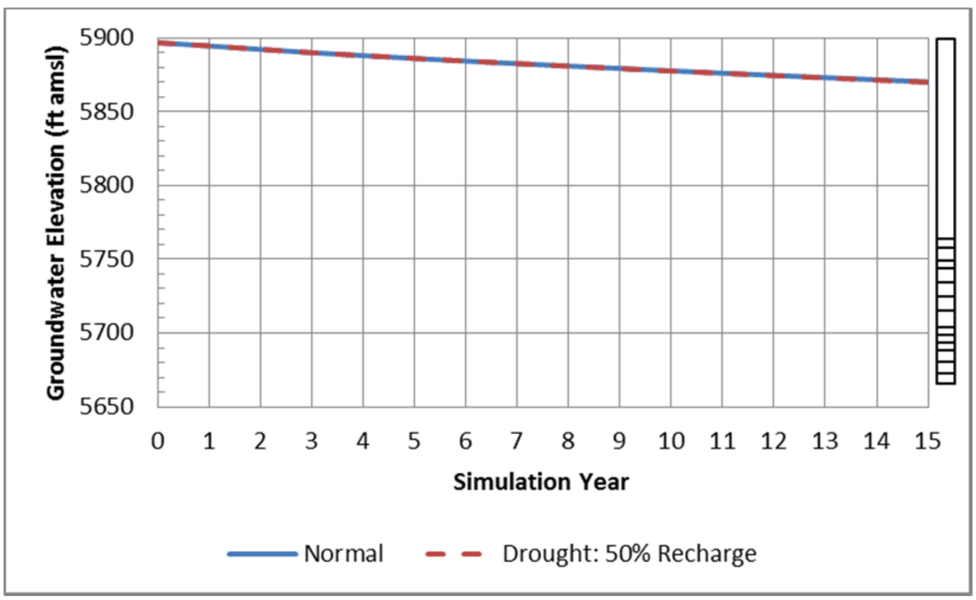

Figure 5. Plot of groundwater elevation at well DV#2 as a function of time under normal recharge conditions and under drought conditions represented by a 50 percent recharge scenario. The elevation of the screened interval of the well is shown on the right.

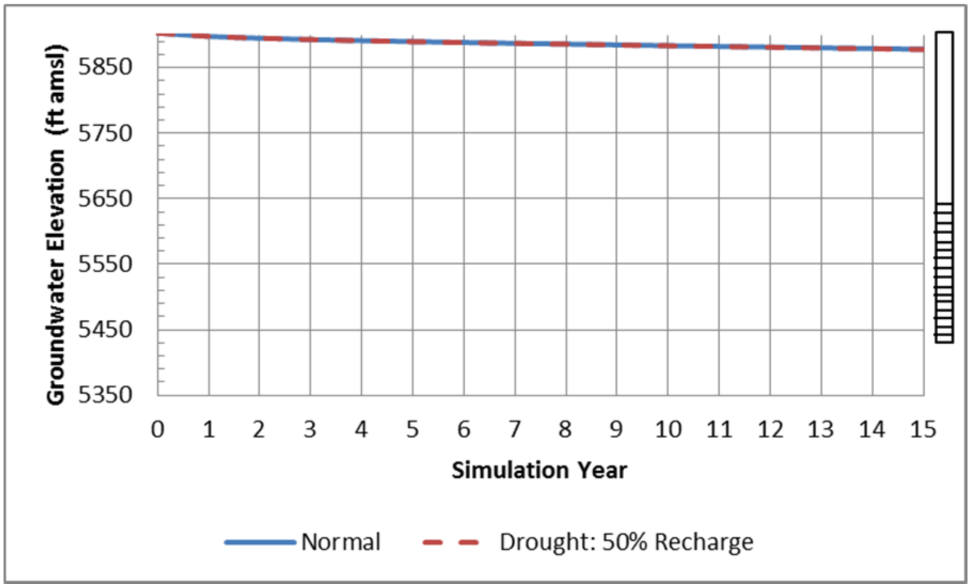

Figure 6. Plot of groundwater elevation at the DV Airport well as a function of time under normal recharge conditions and under drought conditions represented by a 50 percent recharge scenario. The elevation of the screened interval of the well is shown on the right.

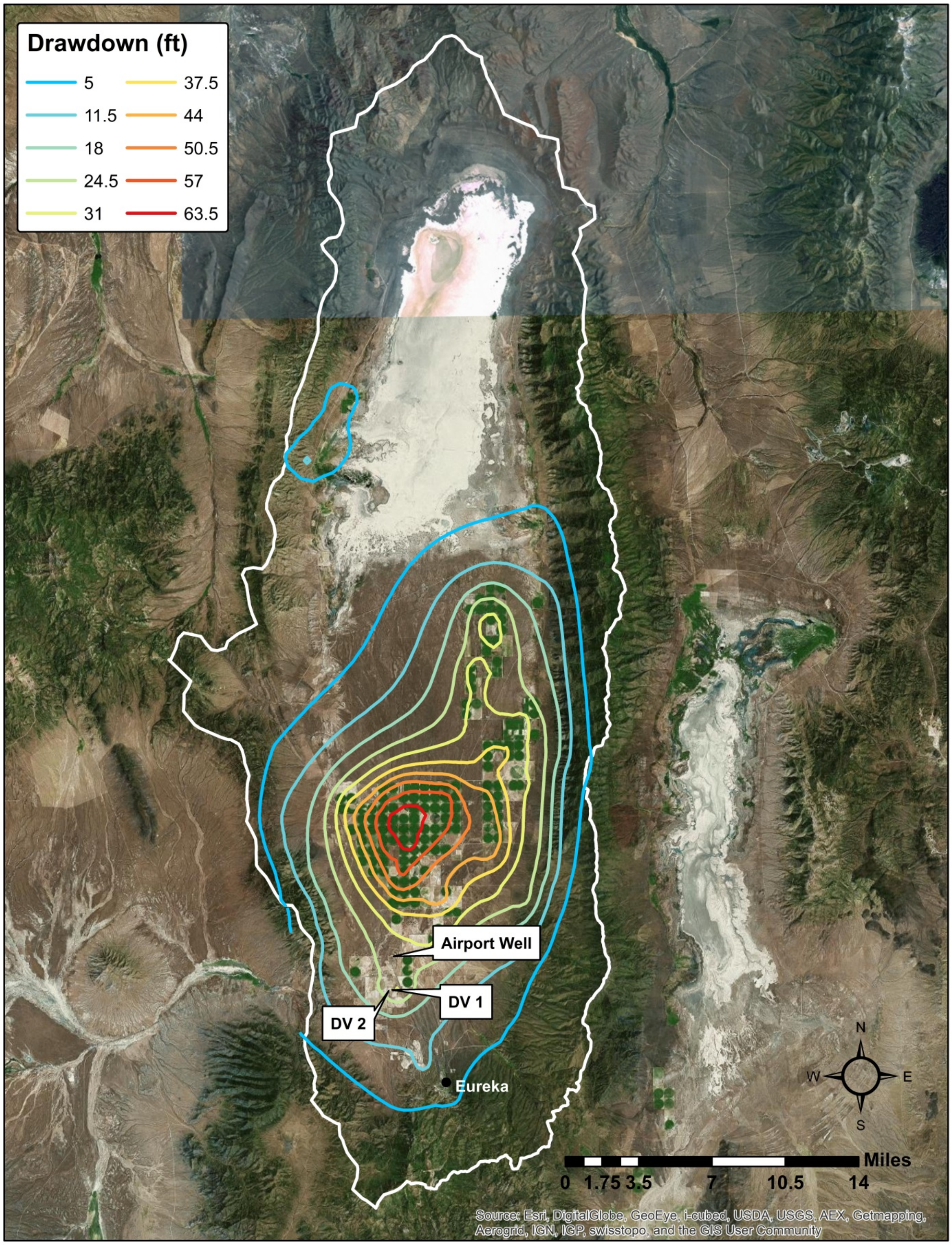

Figure 7. Drawdown in Diamond Valley after 15 years of mountain block recharge set to 100% of normal, all wells pumping at full water right.

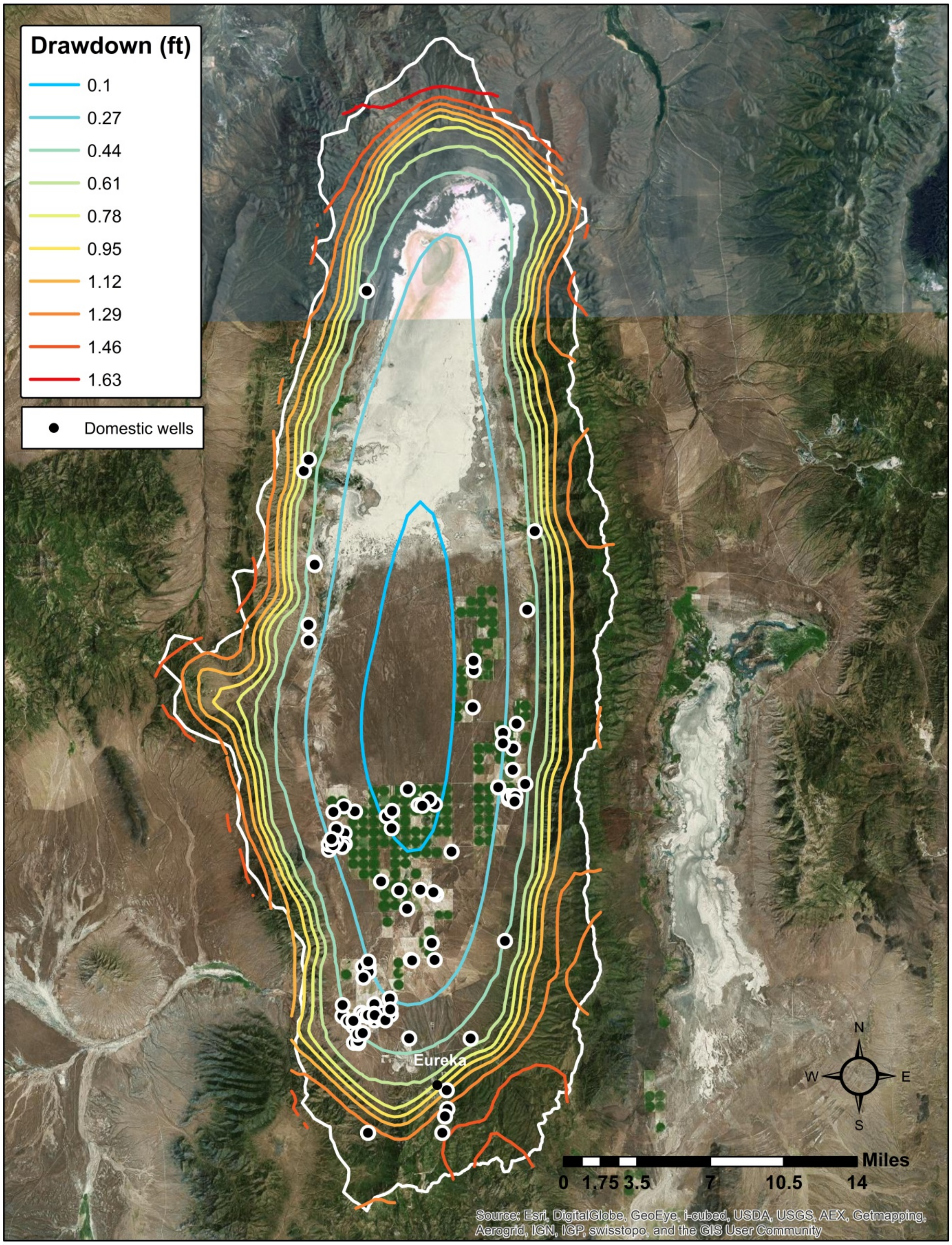

Figure 8. Difference in Diamond Valley drawdown between simulation using 100% of normal recharge and simulation using 50% of normal recharge, all wells pumping at full water right.

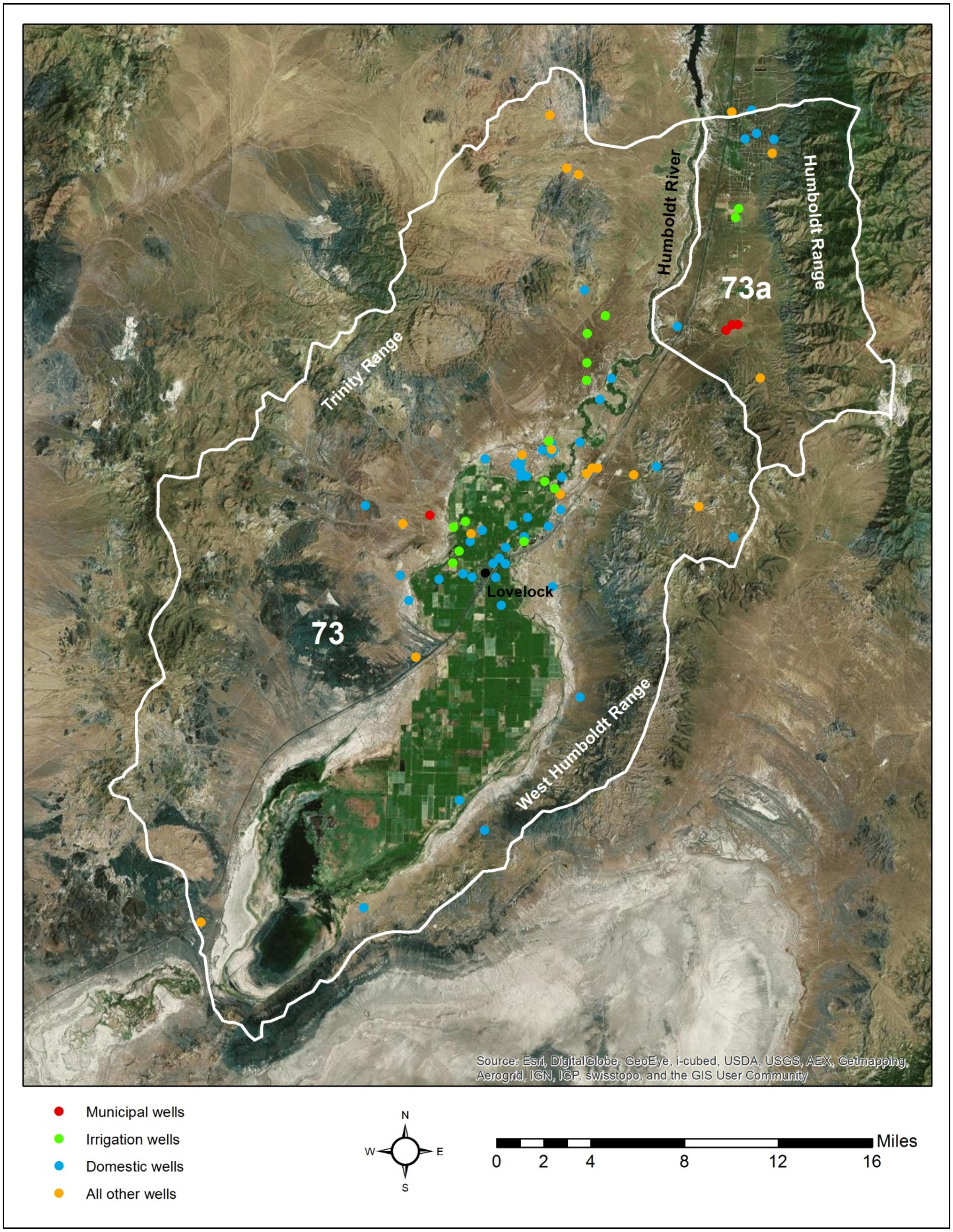

Figure 9. Lovelock Valley (73) , the Oreana sub-area (73a), and locations of wells used in transient simulations.

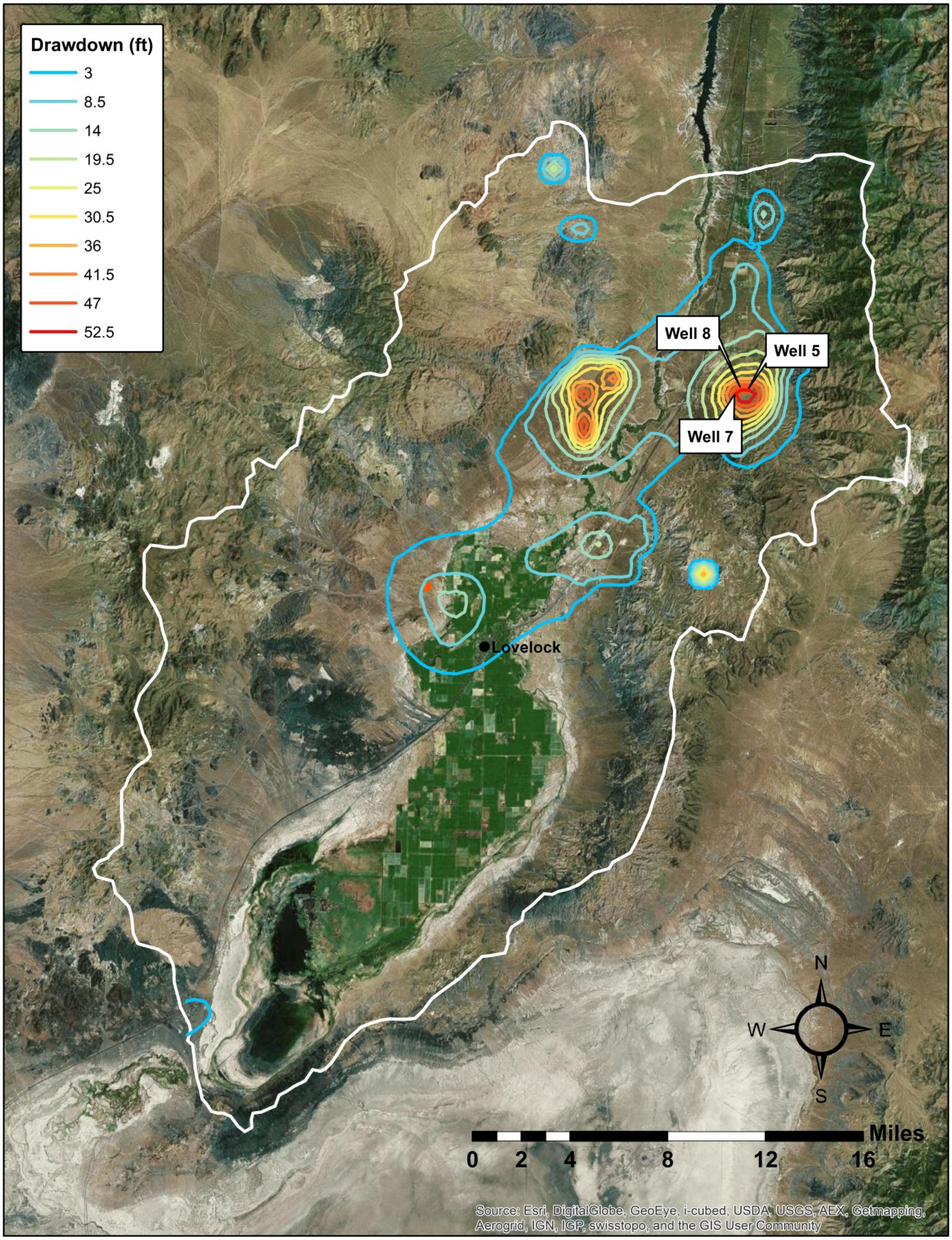

Figure 10. Drawdown in Lovelock Valley after 15 years of mountain block recharge set to 100% of normal, all wells pumping at full water right.

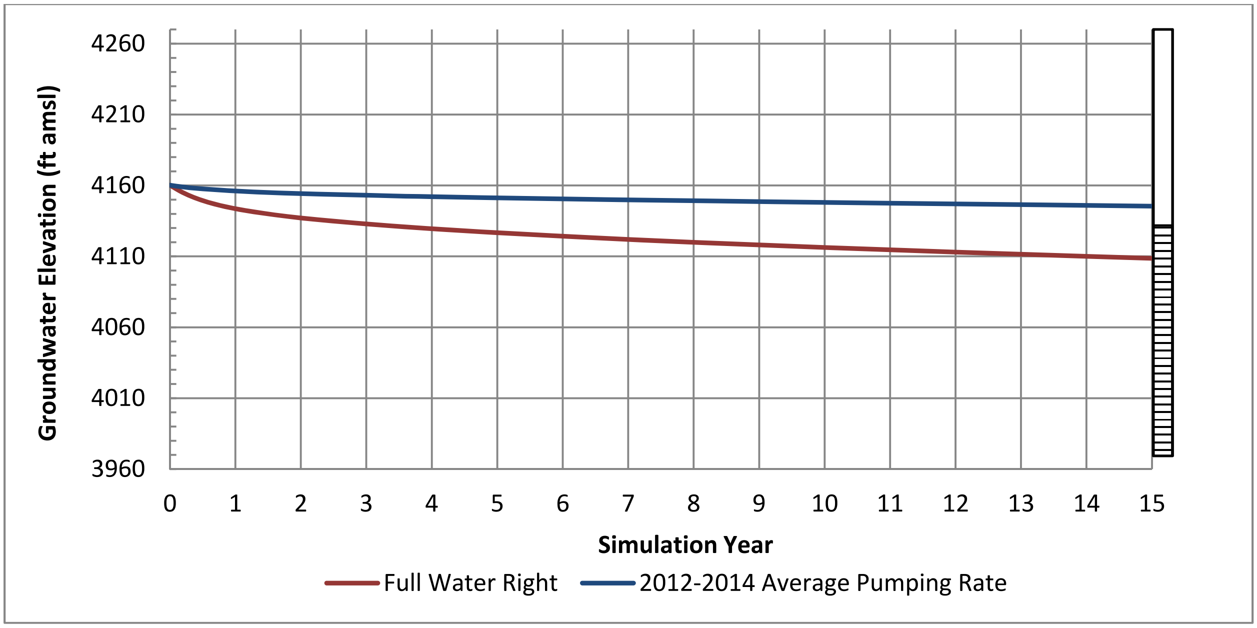

Figure 11. Declines in groundwater levels at Well 7. Total depth of well and screened interval indicated at right.

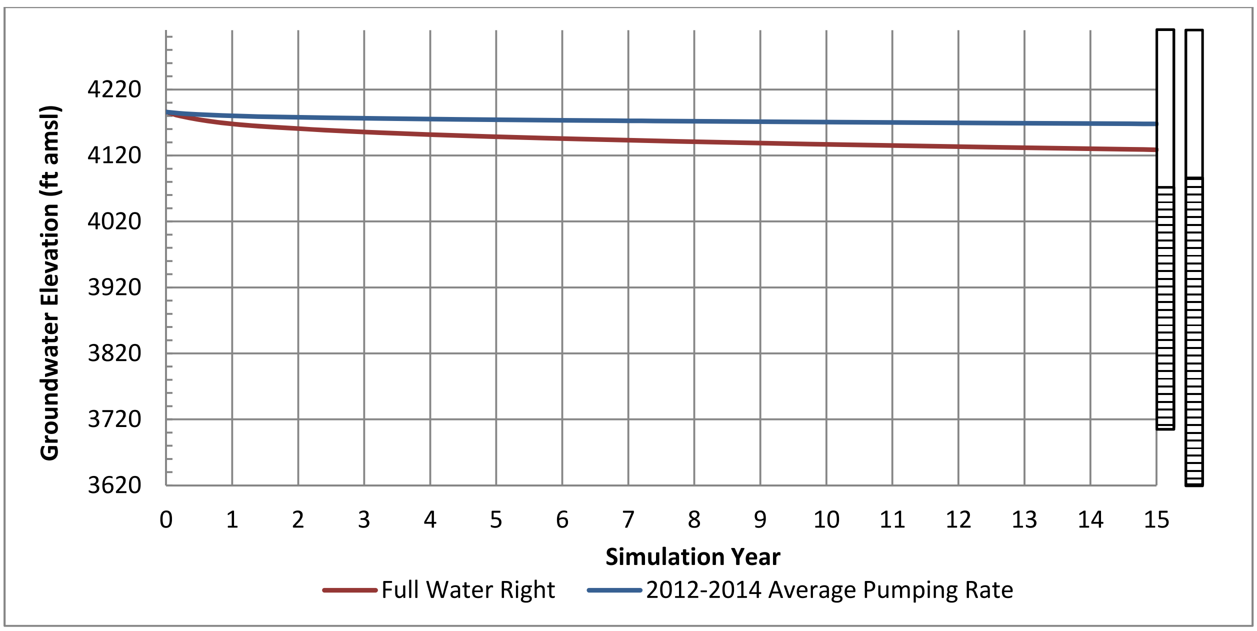

Figure 12. Declines in groundwater levels at Wells 5 and 8. Total depths of wells and screened intervals for Wells 5 and 8, respectively, indicated at right.

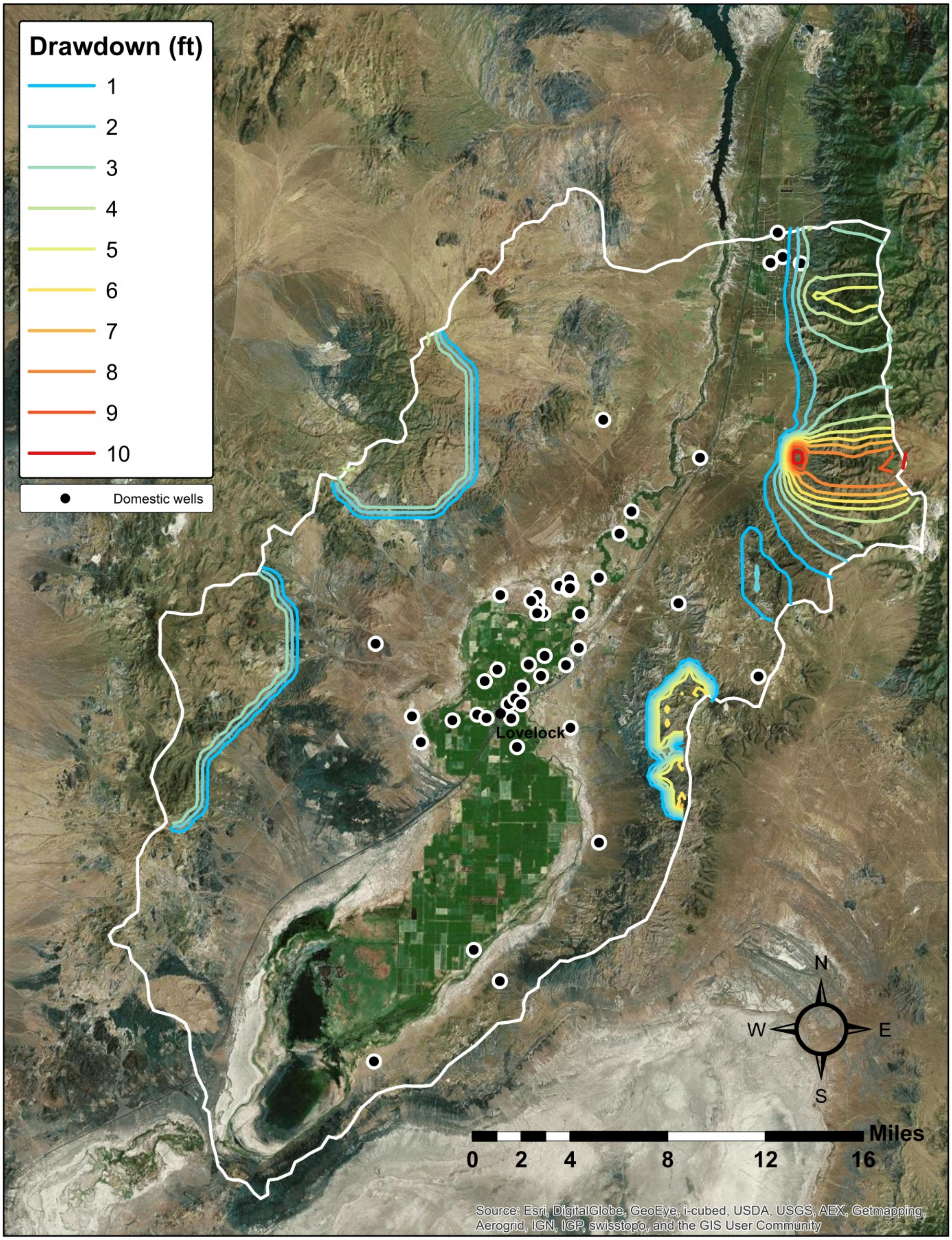

Figure 13. Difference in Lovelock Valley drawdown between simulation using 100% of normal recharge and simulation using 50% of normal recharge, all wells pumping at full water right.

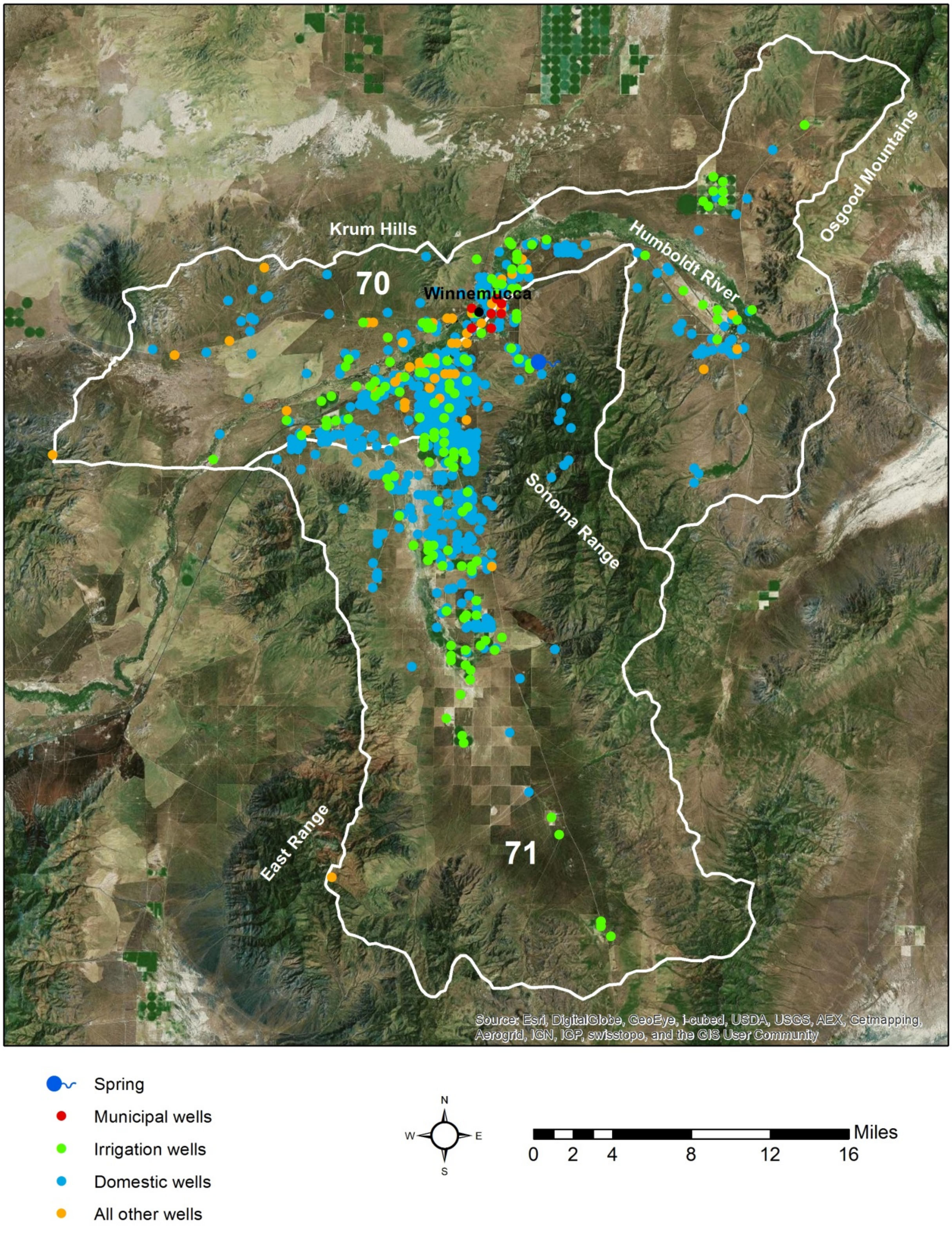

Figure 14. Winnemucca Segment (70) and Grass Valley (71) and locations of wells and springs used in transient simulations.

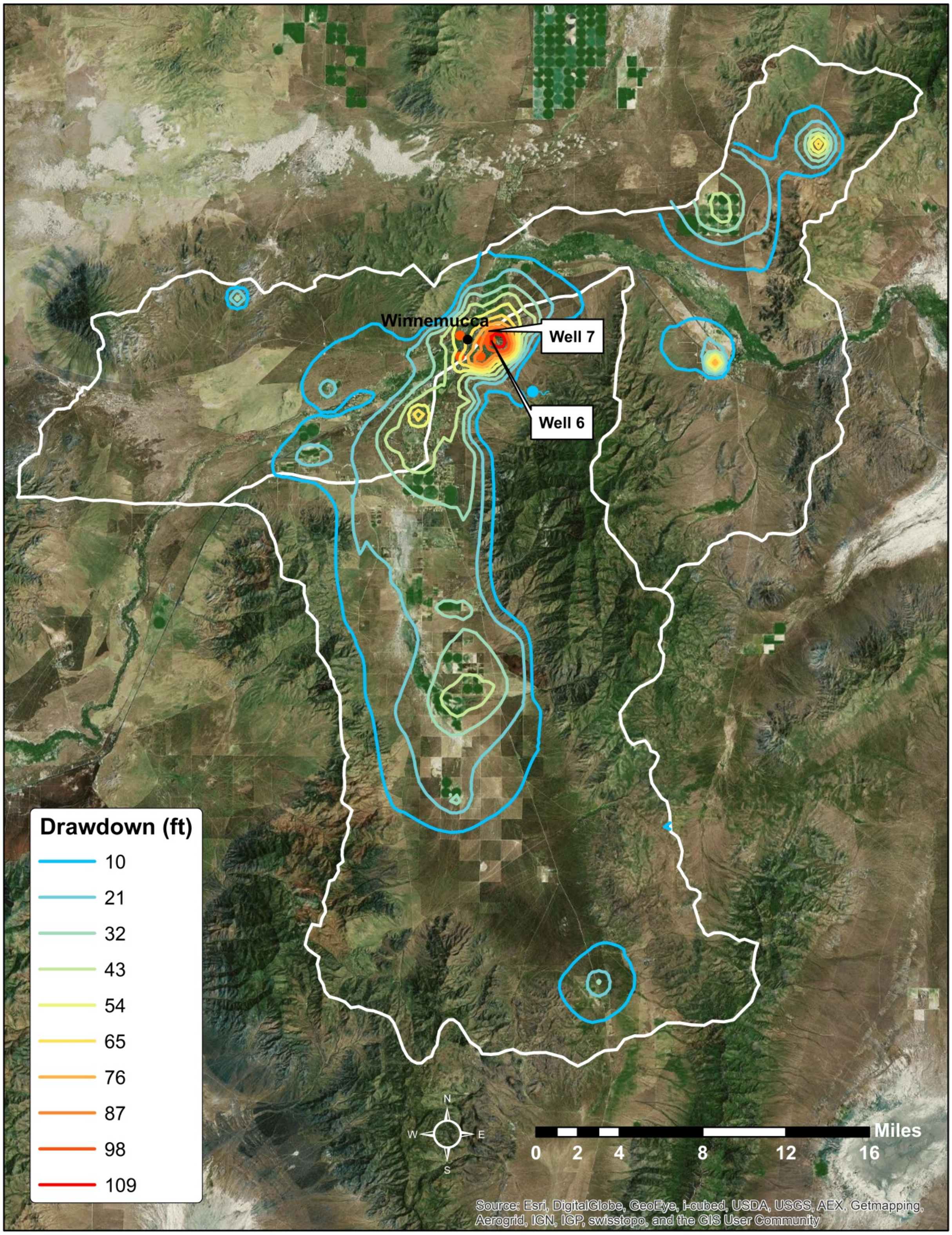

Figure 15. Drawdown in the Winnemucca Segment and Grass Valley after 15 years of mountain block recharge set to 100% of normal, all wells pumping at full water right.

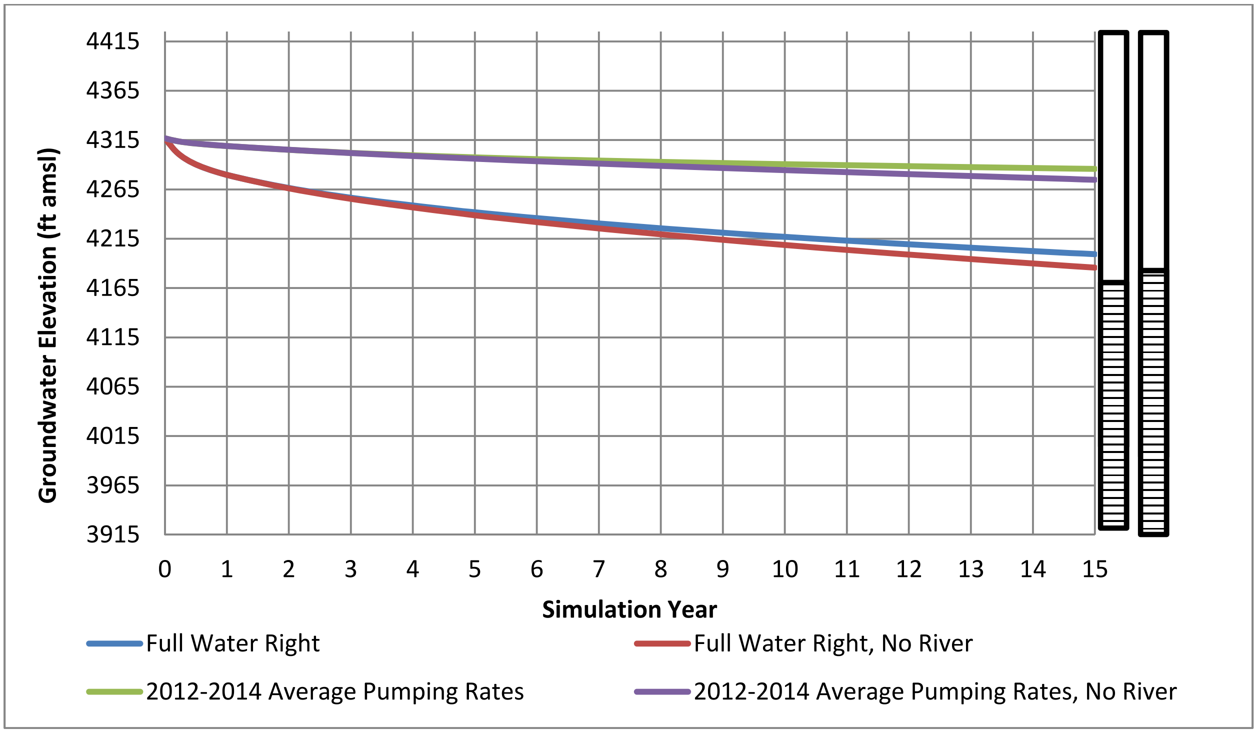

Figure 16. Declines in groundwater levels at Wells 6 and 7. Total depths of wells and screened intervals for Wells 6 and 7, respectively, indicated at right.

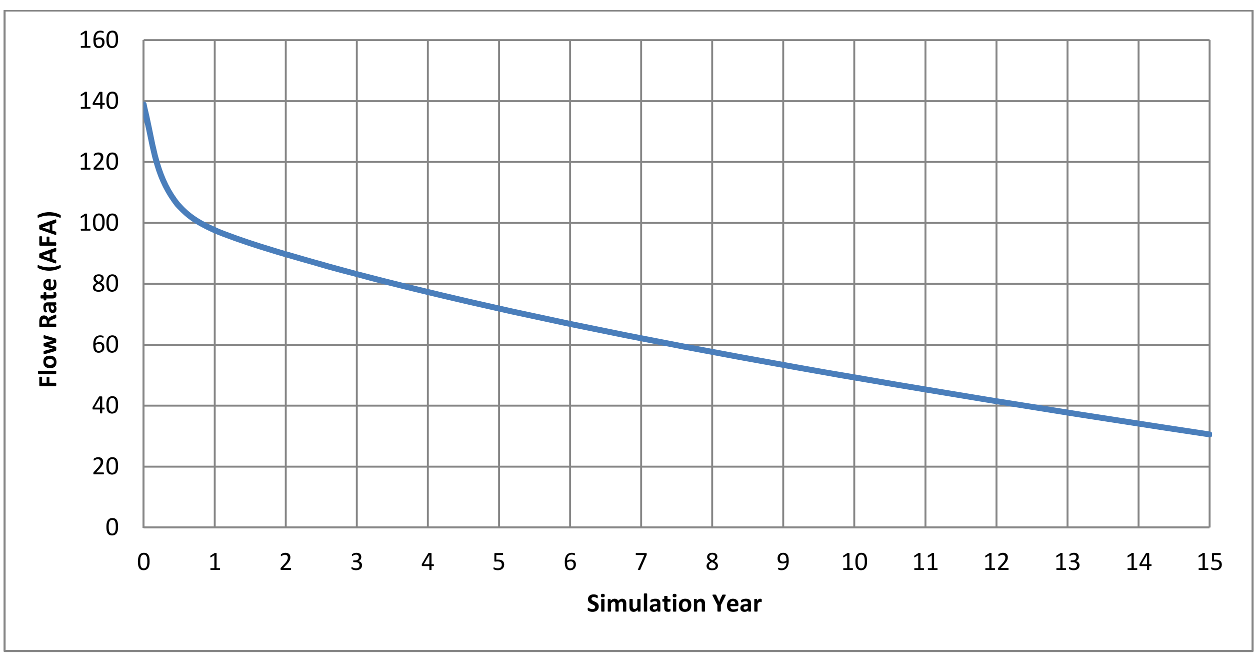

Figure 17. Declines in flow rate for mountain spring in the Winnemucca Segment/Grass Valley simulation.

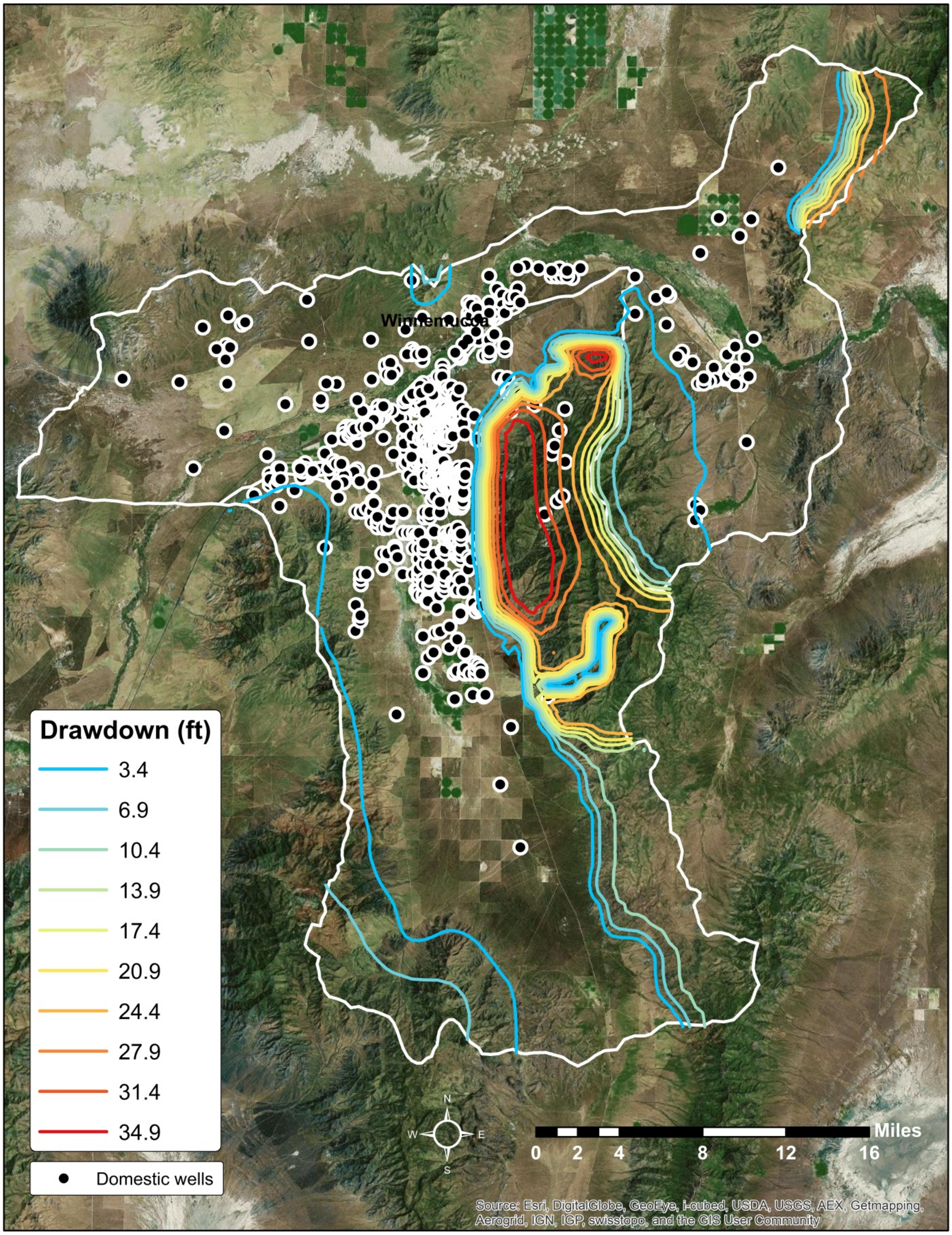

Figure 18. Difference in Winnemucca Segment / Grass Valley drawdown between simulation using 100% of normal recharge and simulation using 50% of normal recharge, all wells pumping at full water right.

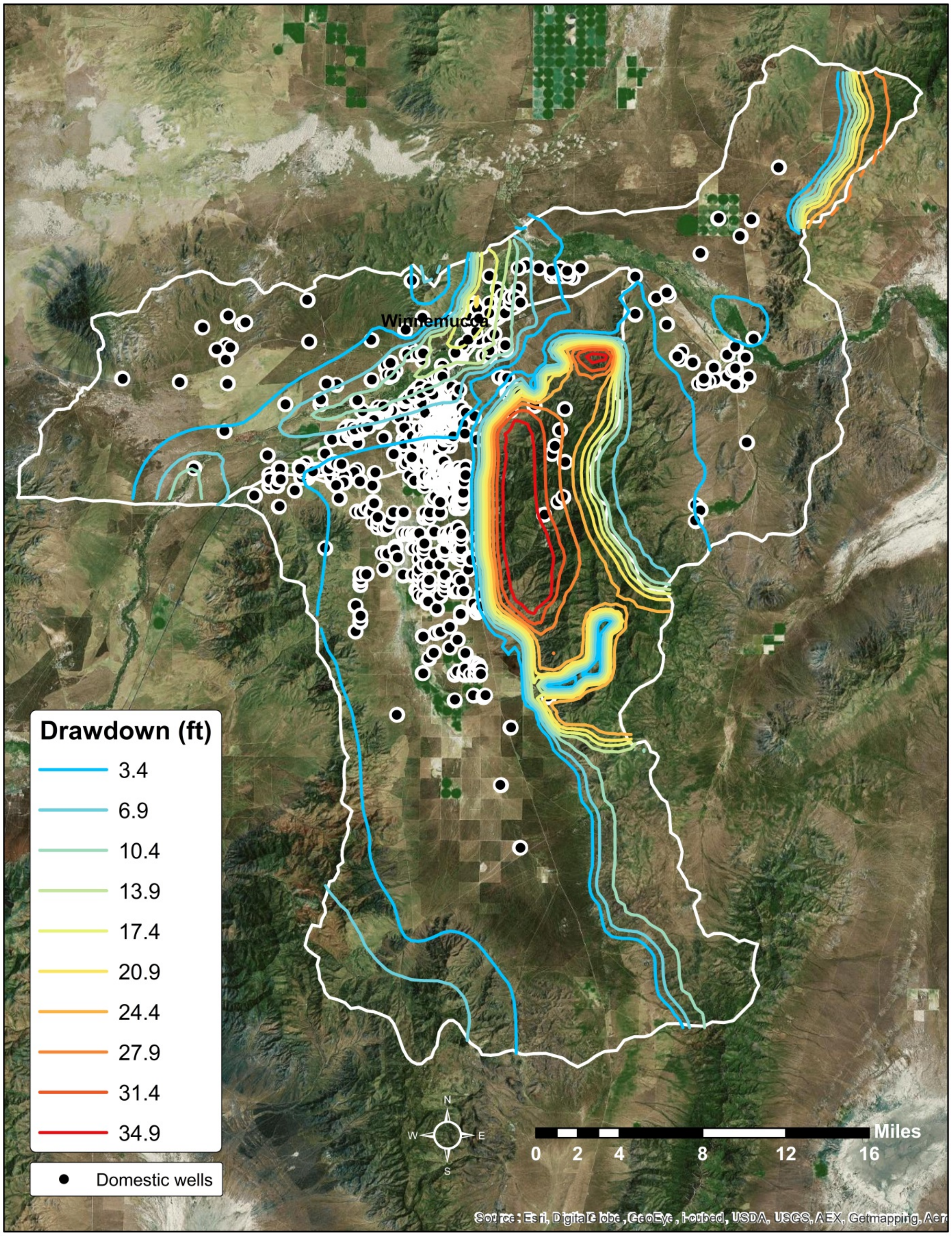

Figure 19. Difference in Winnemucca Segment / Grass Valley drawdown between simulation using 100% of normal recharge and simulation using 50% of normal recharge, all wells pumping at full water right, and river conductance set to zero.

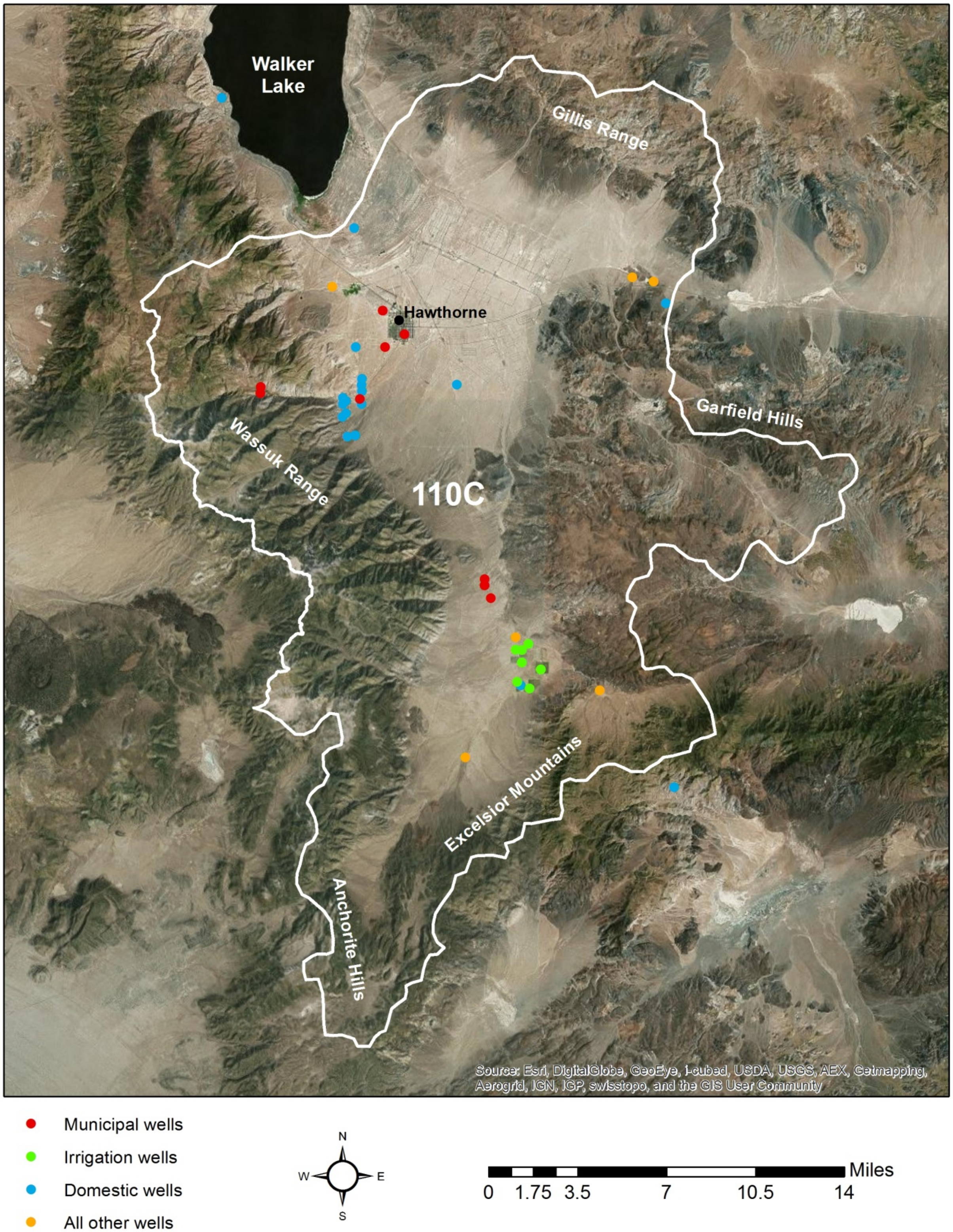

Figure 20. Whiskey Flat-Hawthorne sub-area (110C), and locations of wells used in transient simulations.

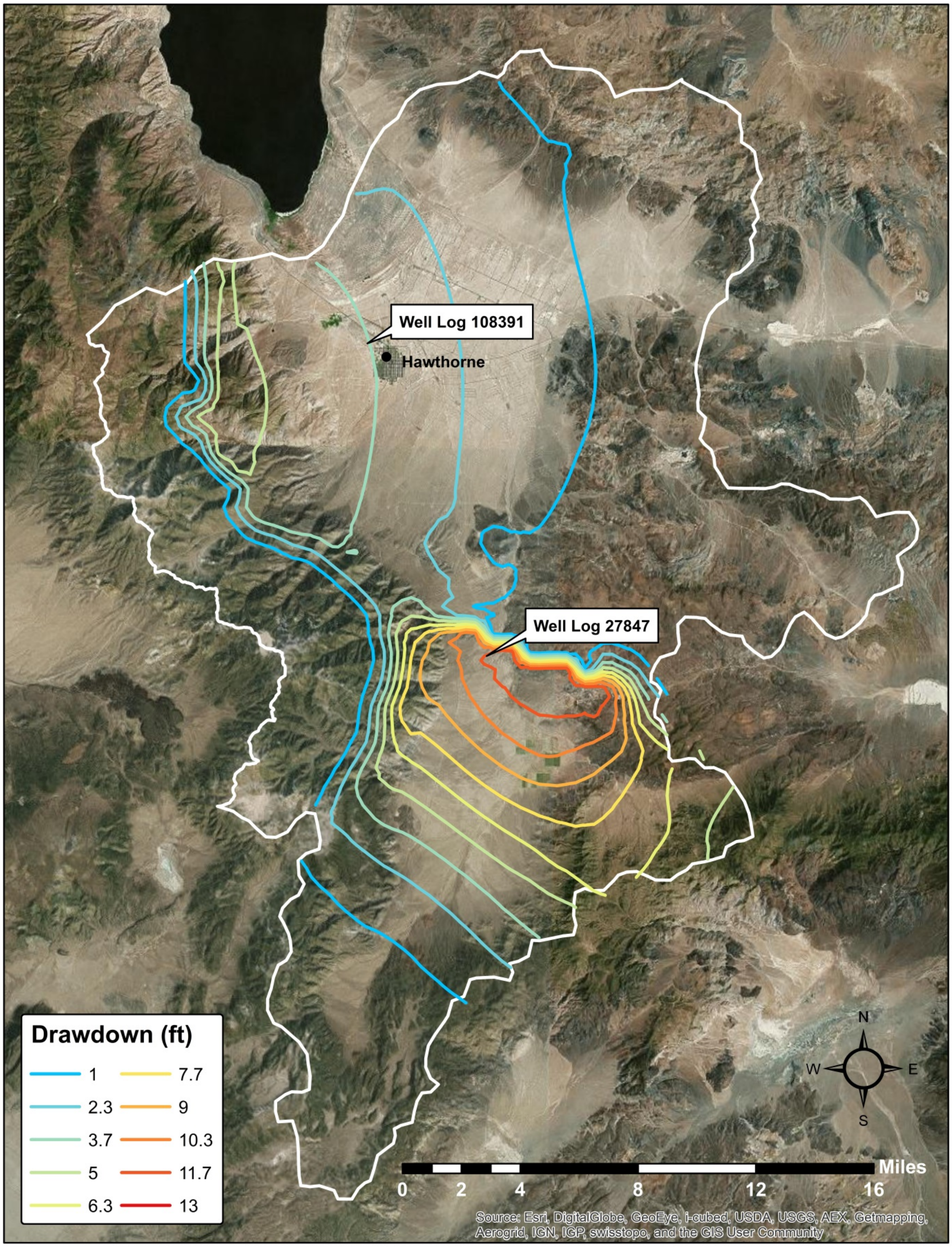

Figure 21. Drawdown in the Whiskey Flat-Hawthorne sub-area after 15 years of mountain block recharge set to 100% of normal, all wells pumping at full water right.

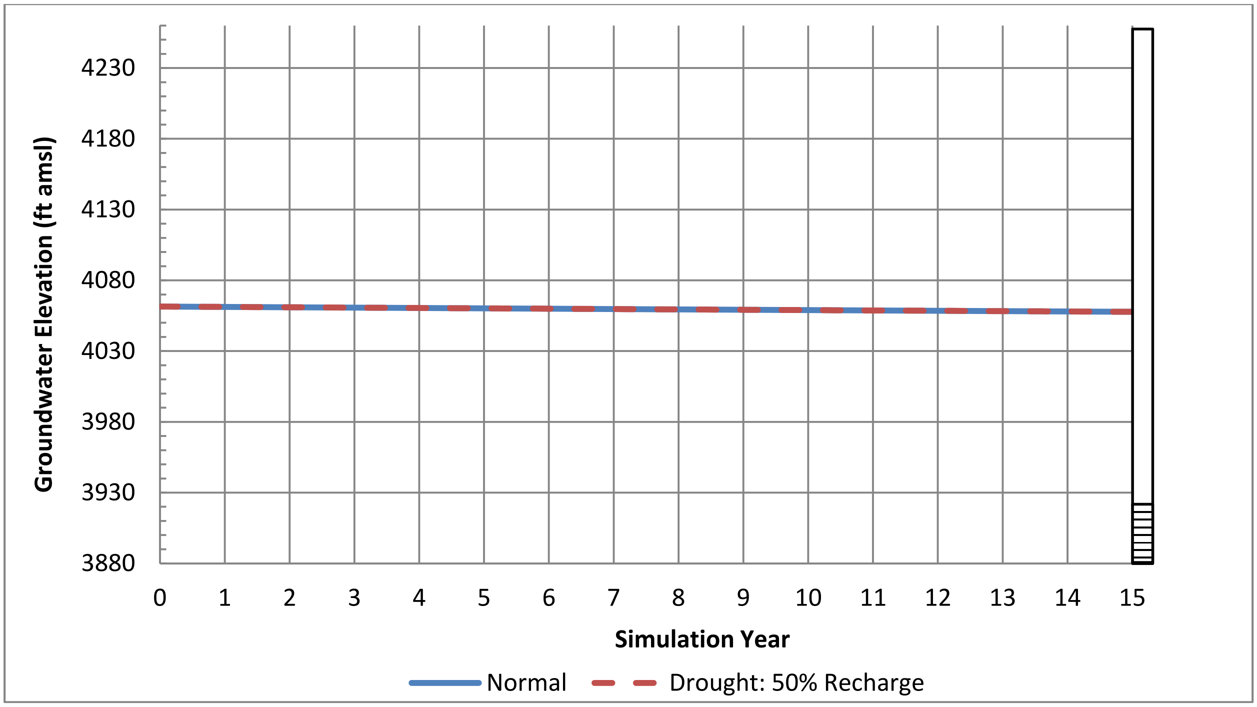

Figure 22. Declines in groundwater levels at well log 108391. Total depths of well and screened intervals indicated at right.

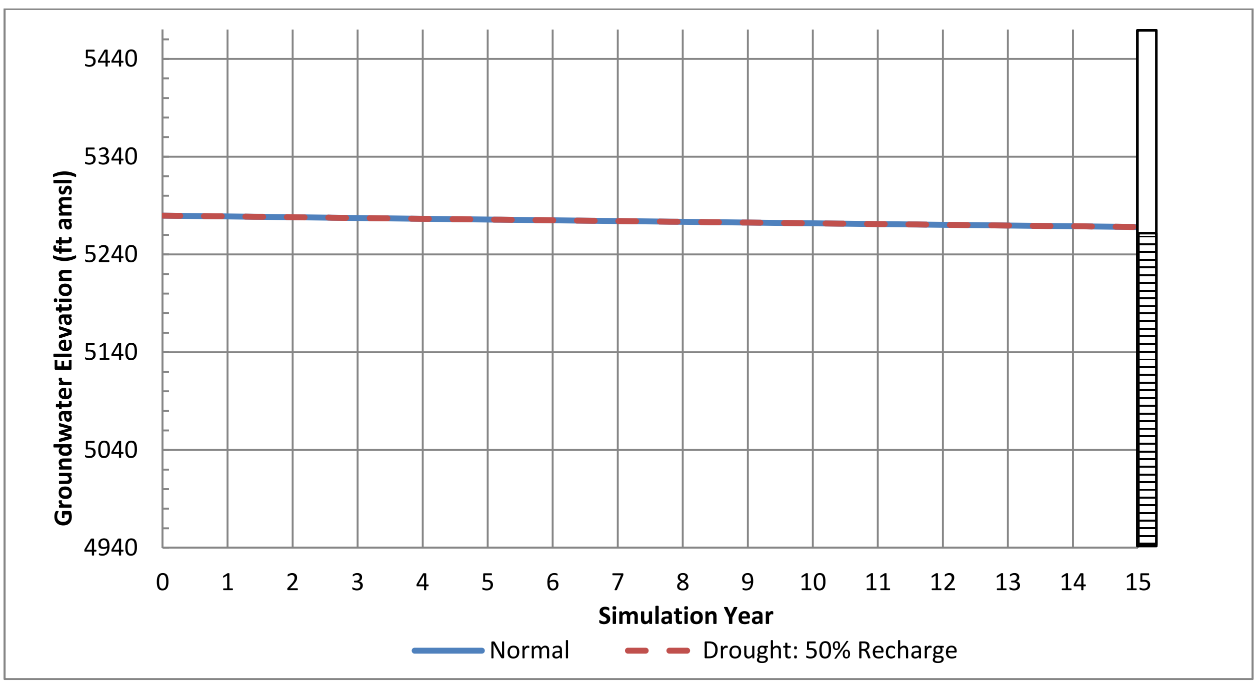

Figure 23. Declines in groundwater levels at well log 27847. Total depths of well and screened intervals indicated at right.

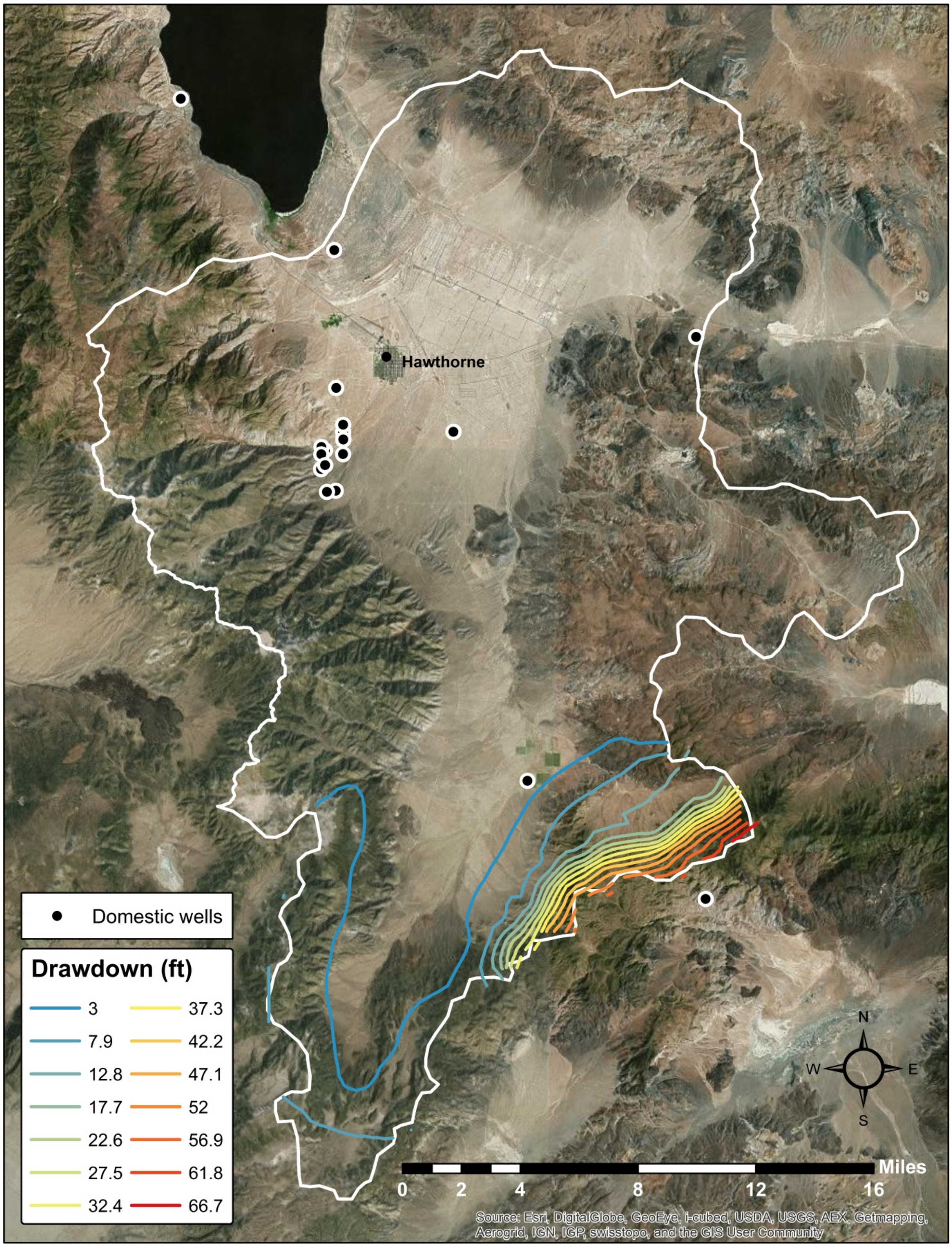

Figure 24. Difference in the Whiskey Flat-Hawthorne sub-area drawdown between simulation using 100% of normal recharge and simulation using 50% of normal recharge, all wells pumping at full water right.

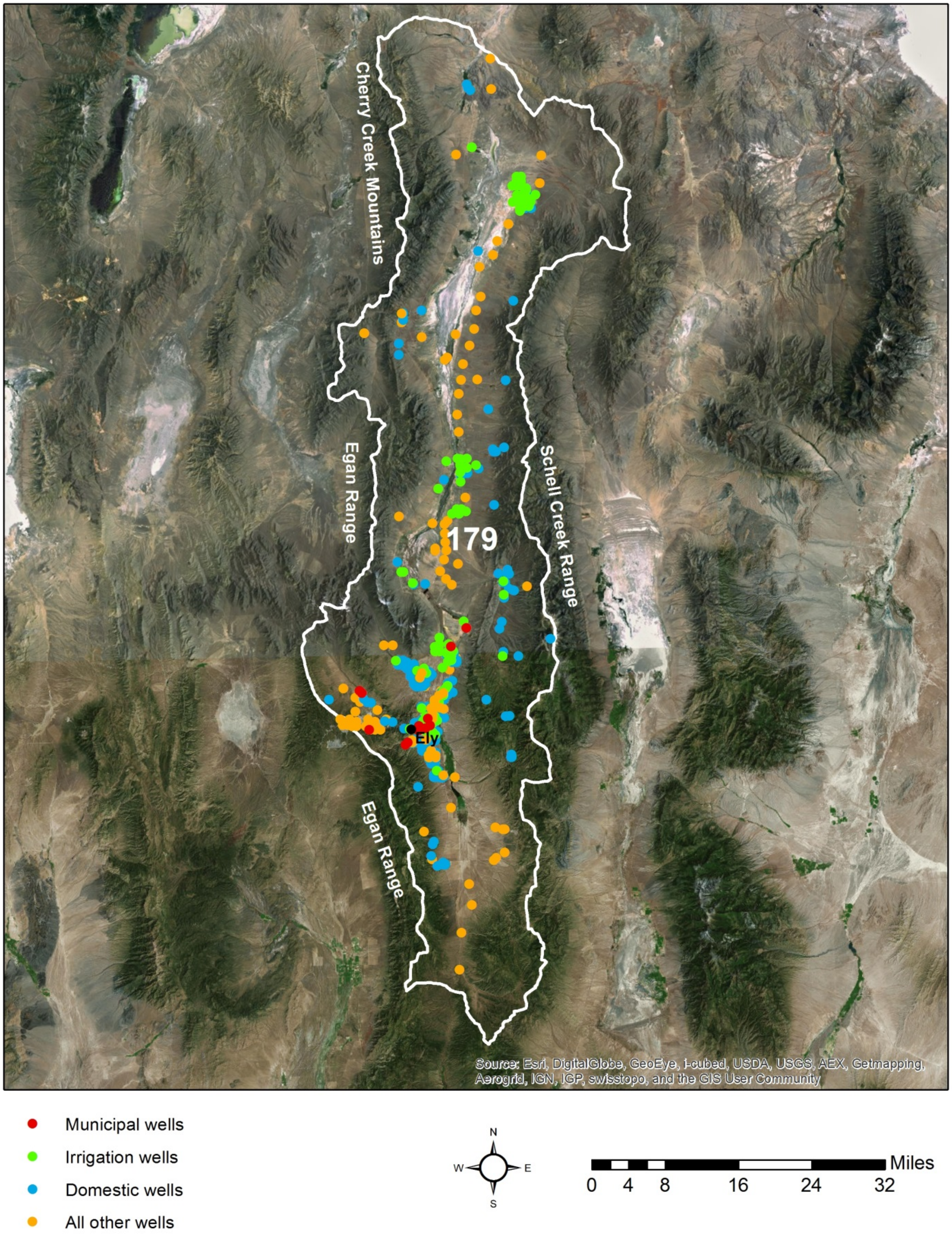

Figure 25. Steptoe Valley (179) and locations of wells used in transient simulations.

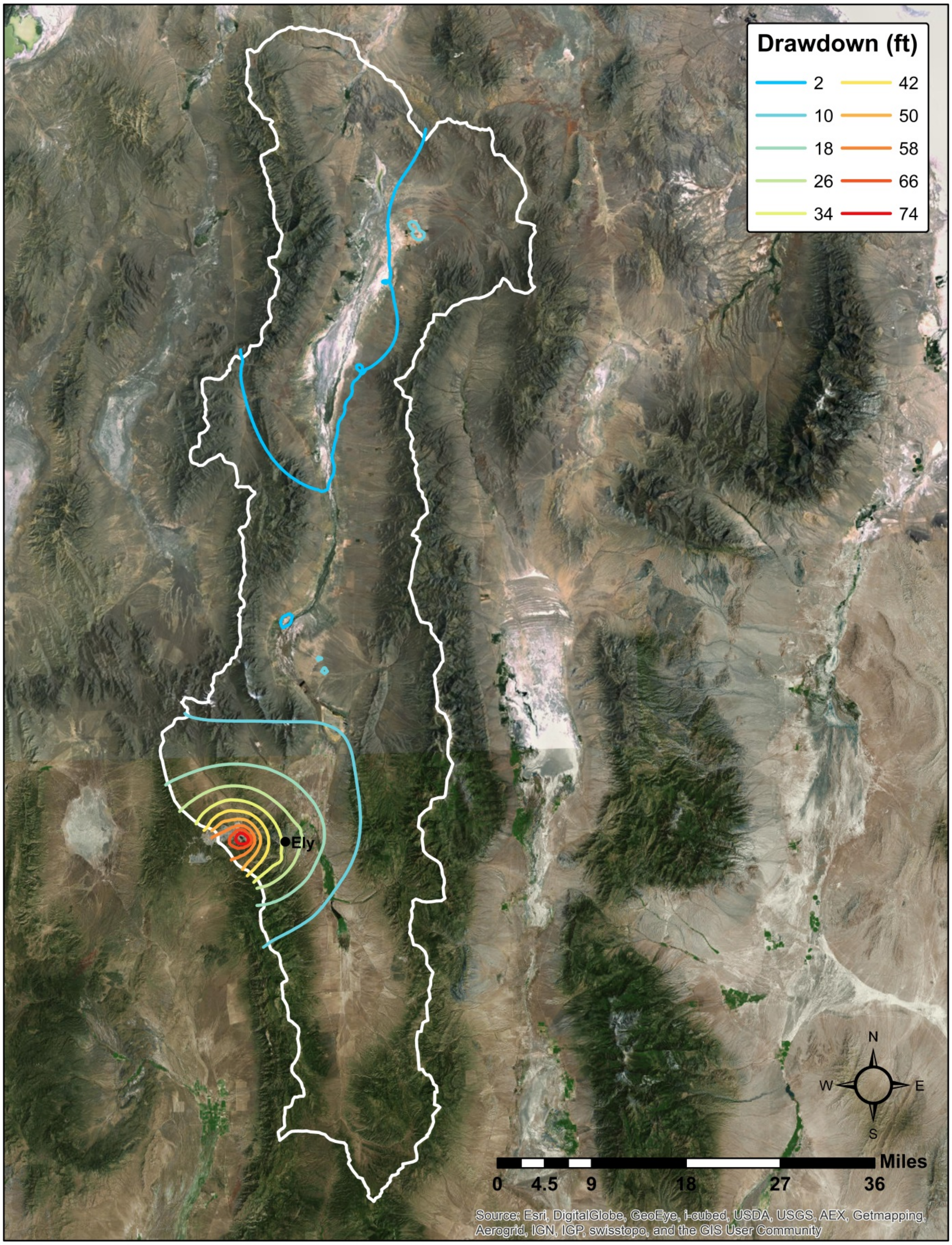

Figure 26. Drawdown in Steptoe valley after 15 years of mountain block recharge set to 100% of normal, all wells pumping at full water right.

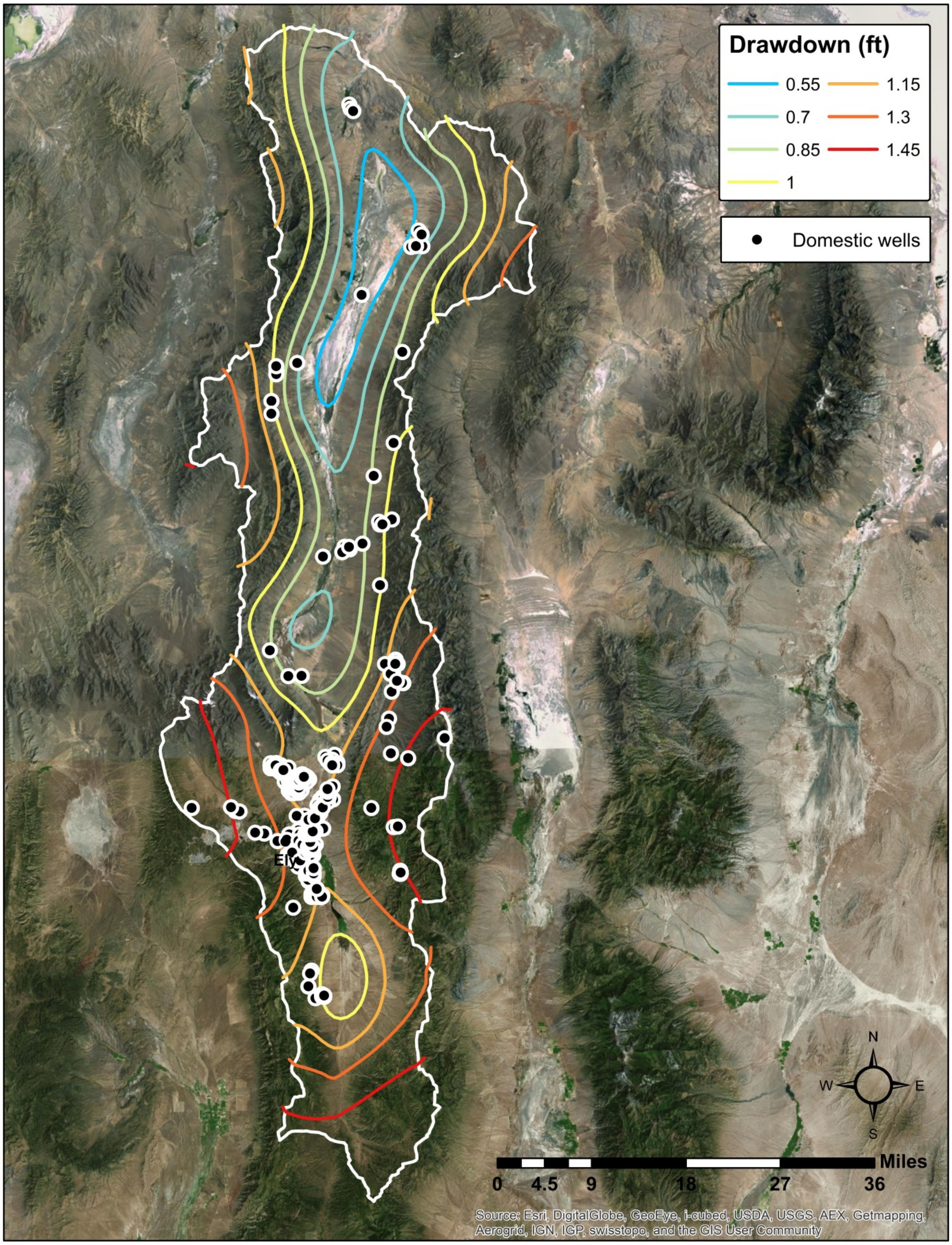

Figure 27. Difference in Steptoe Valley drawdown between simulation using 100% of normal recharge and simulation using 50% of normal recharge, all wells pumping at full water right.

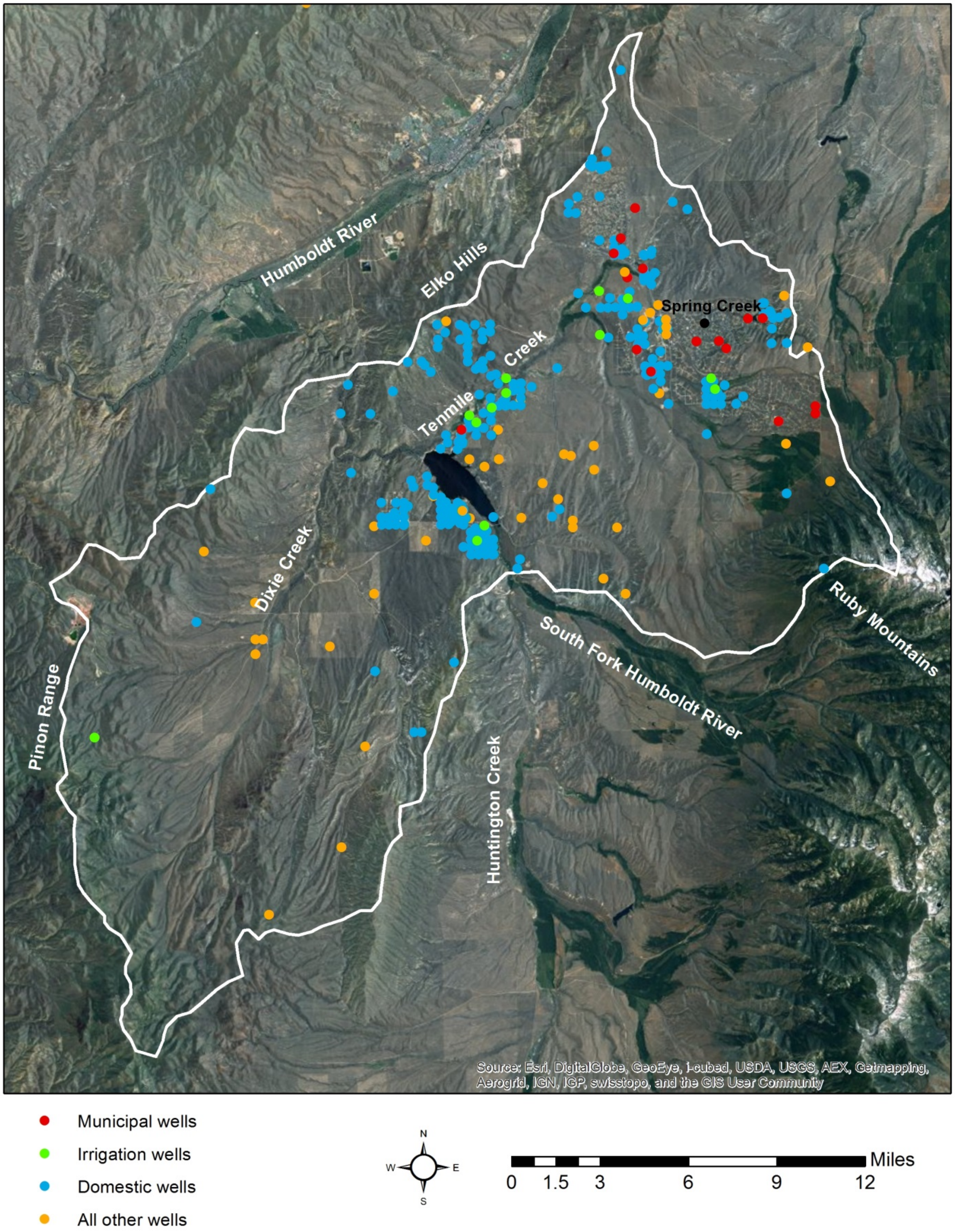

Figure 28. Dixie Creek-Tenmile Creek area (48), and locations of wells used in transient simulations.

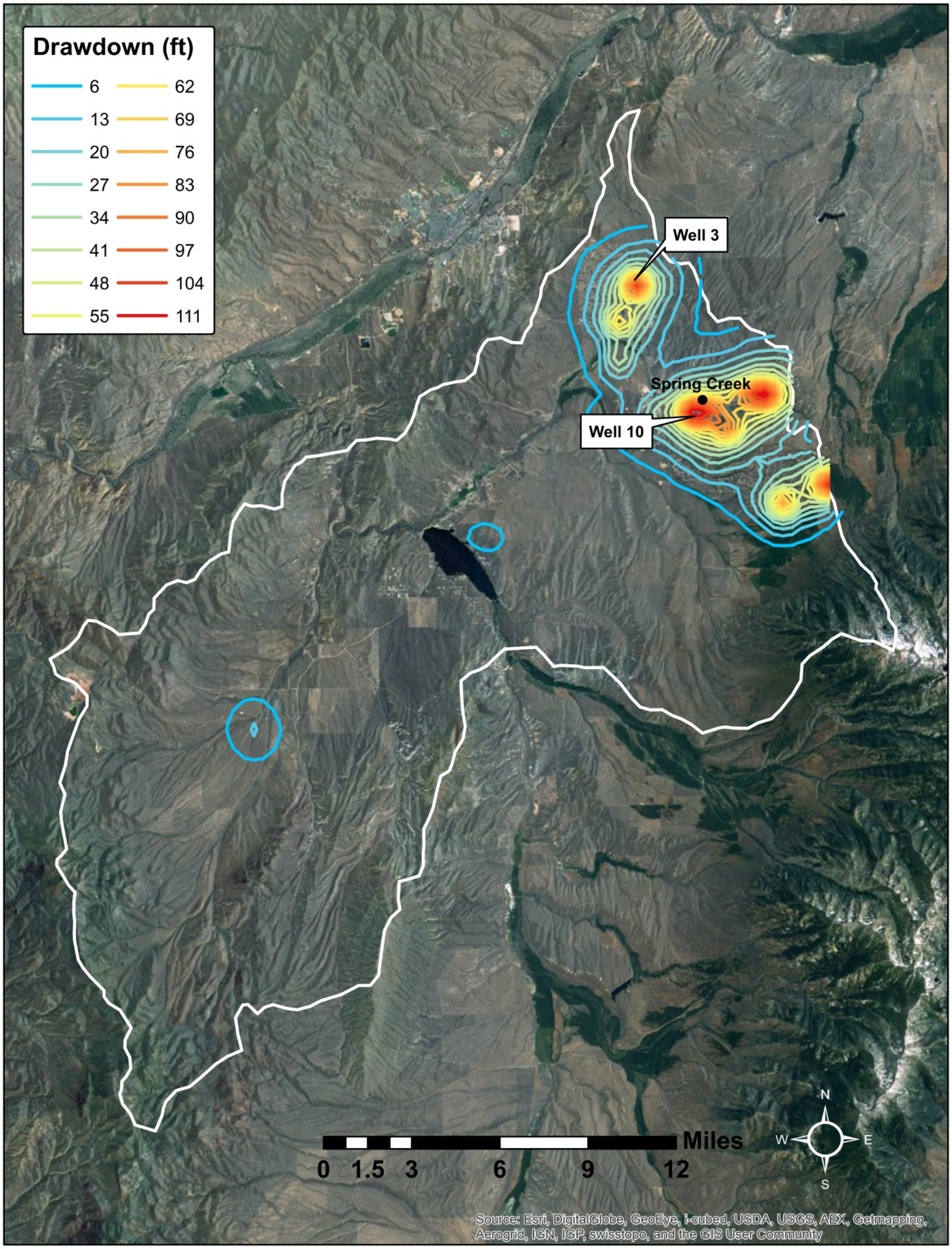

Figure 29. Drawdown in the Dixie Creek-Tenmile Creek area after 15 years of mountain block recharge set to 100% of normal, all wells pumping at full water right.

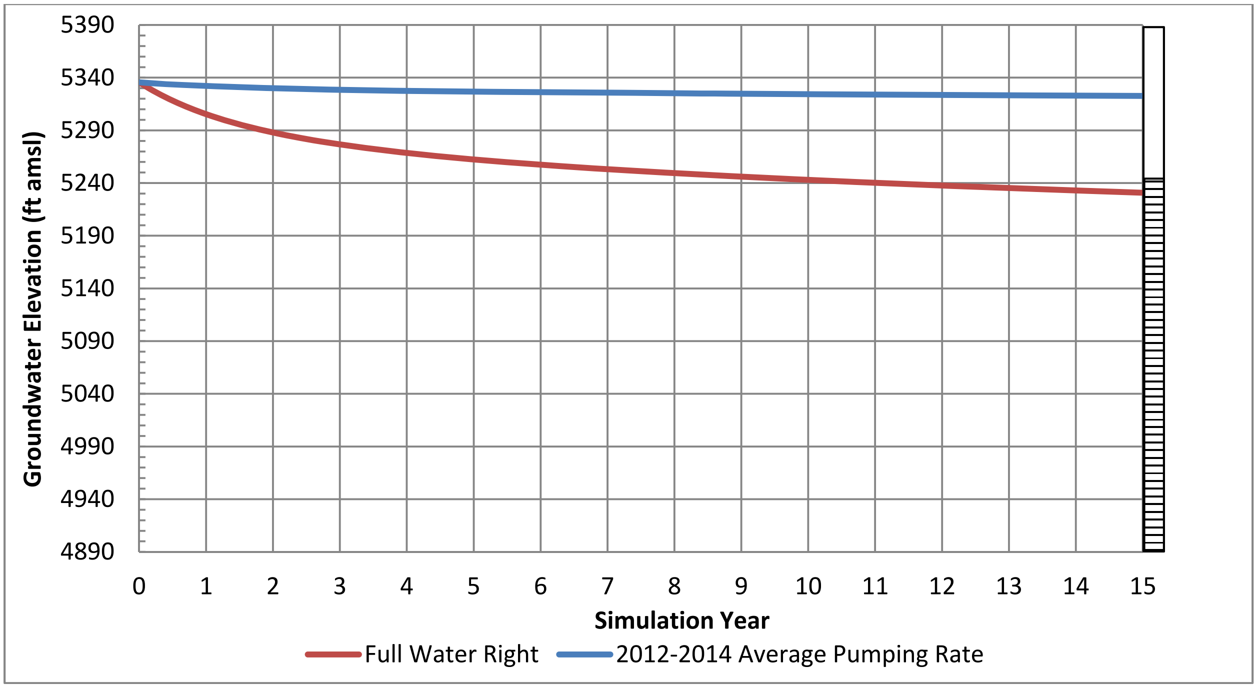

Figure 30. Declines in groundwater levels at Well 3. Total depth of well and screened interval indicated at right.

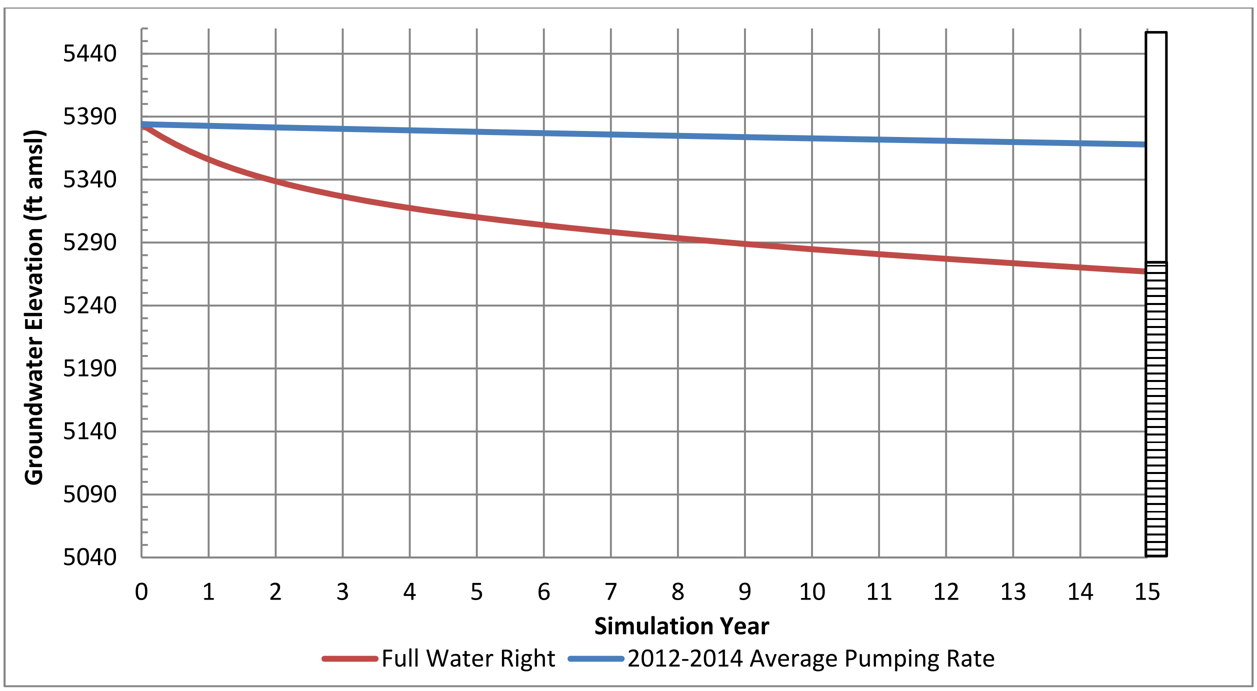

Figure 31. Declines in groundwater levels at Well 10. Total depth of well and screened interval indicated at right.

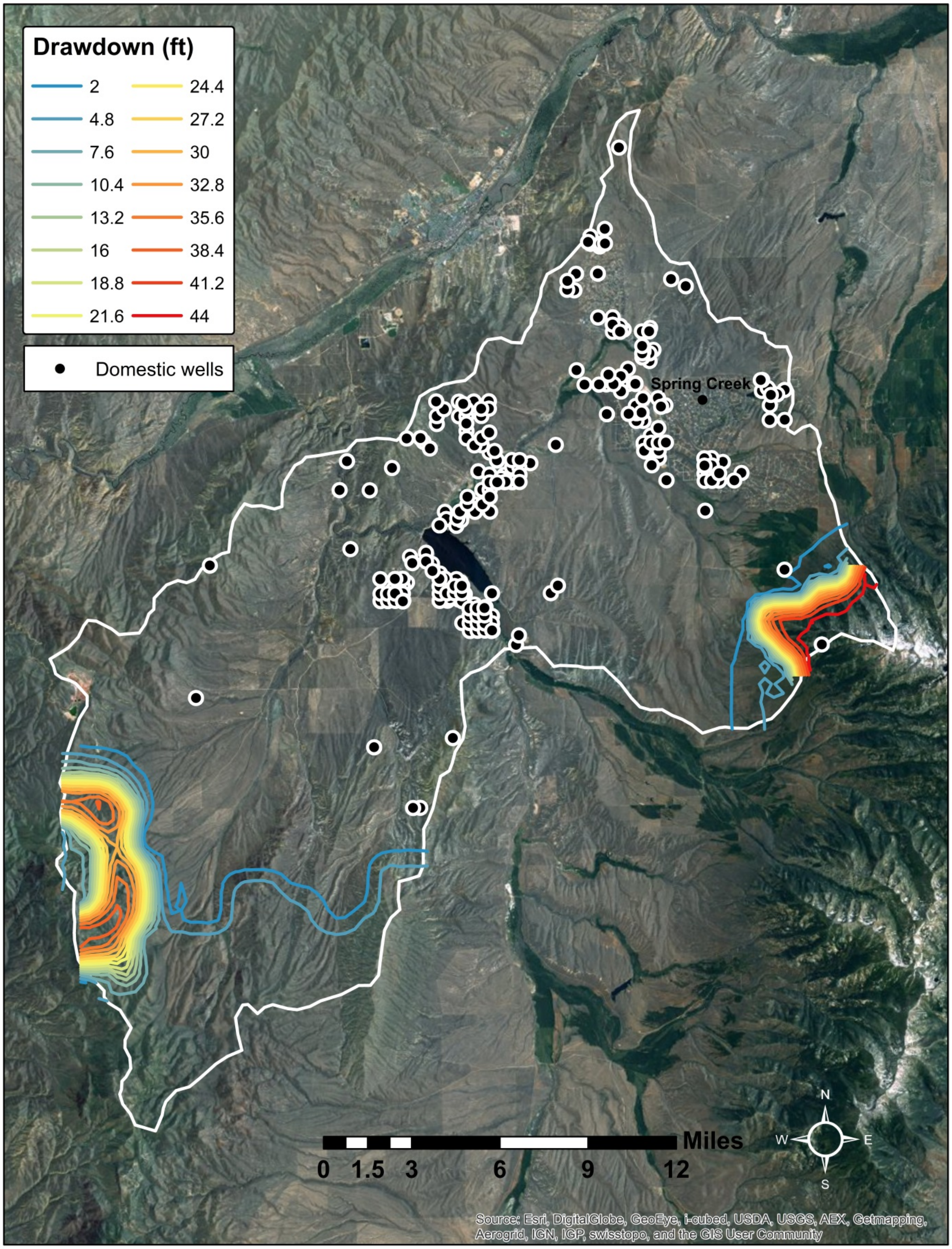

Figure 32. Difference in Dixie Creek-Tenmile Creek drawdown between simulation using 100% of normal recharge and simulation using 50% of normal recharge, all wells pumping at full water right.

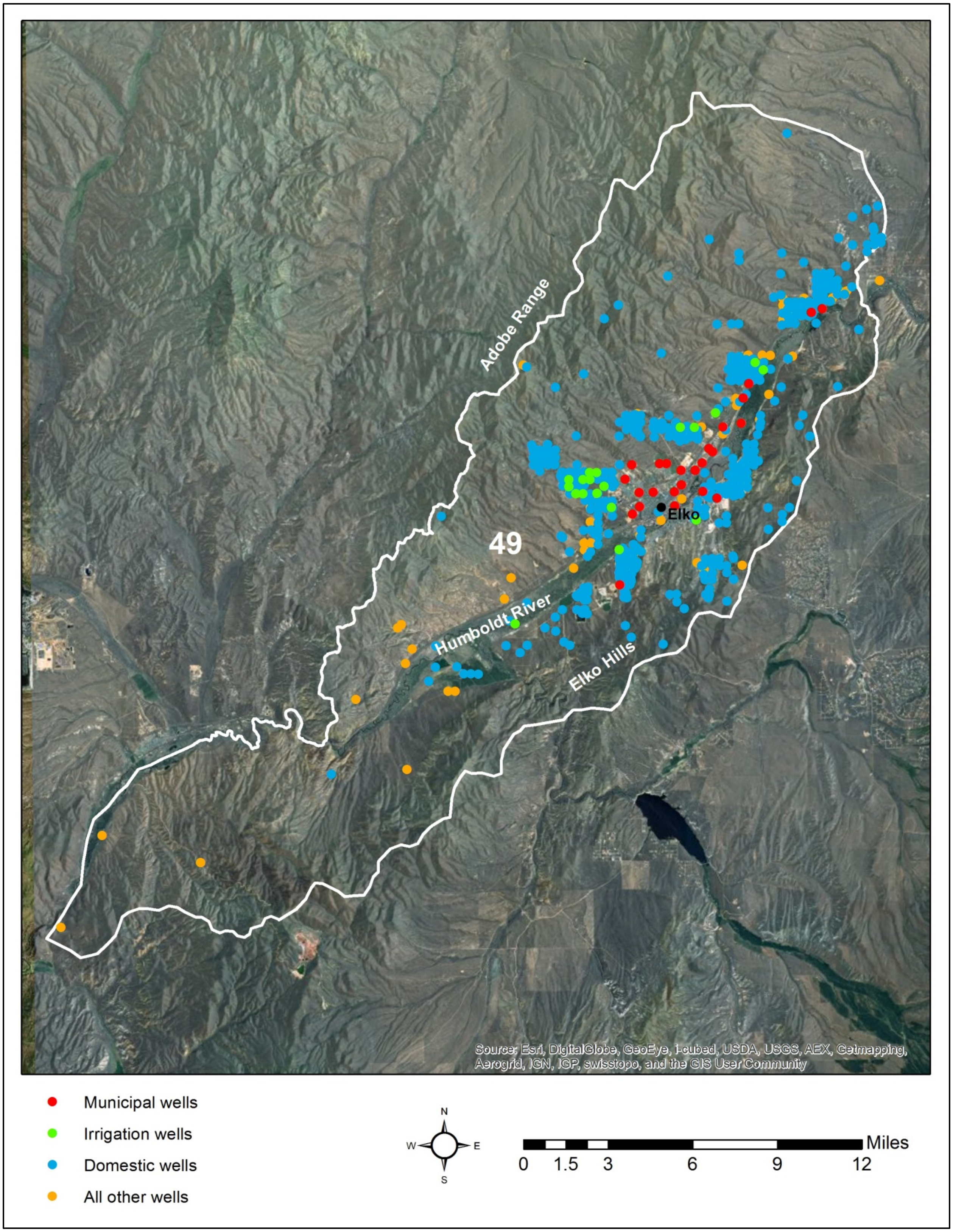

Figure 33. Elko Segment (49), and locations of wells used in transient simulations.

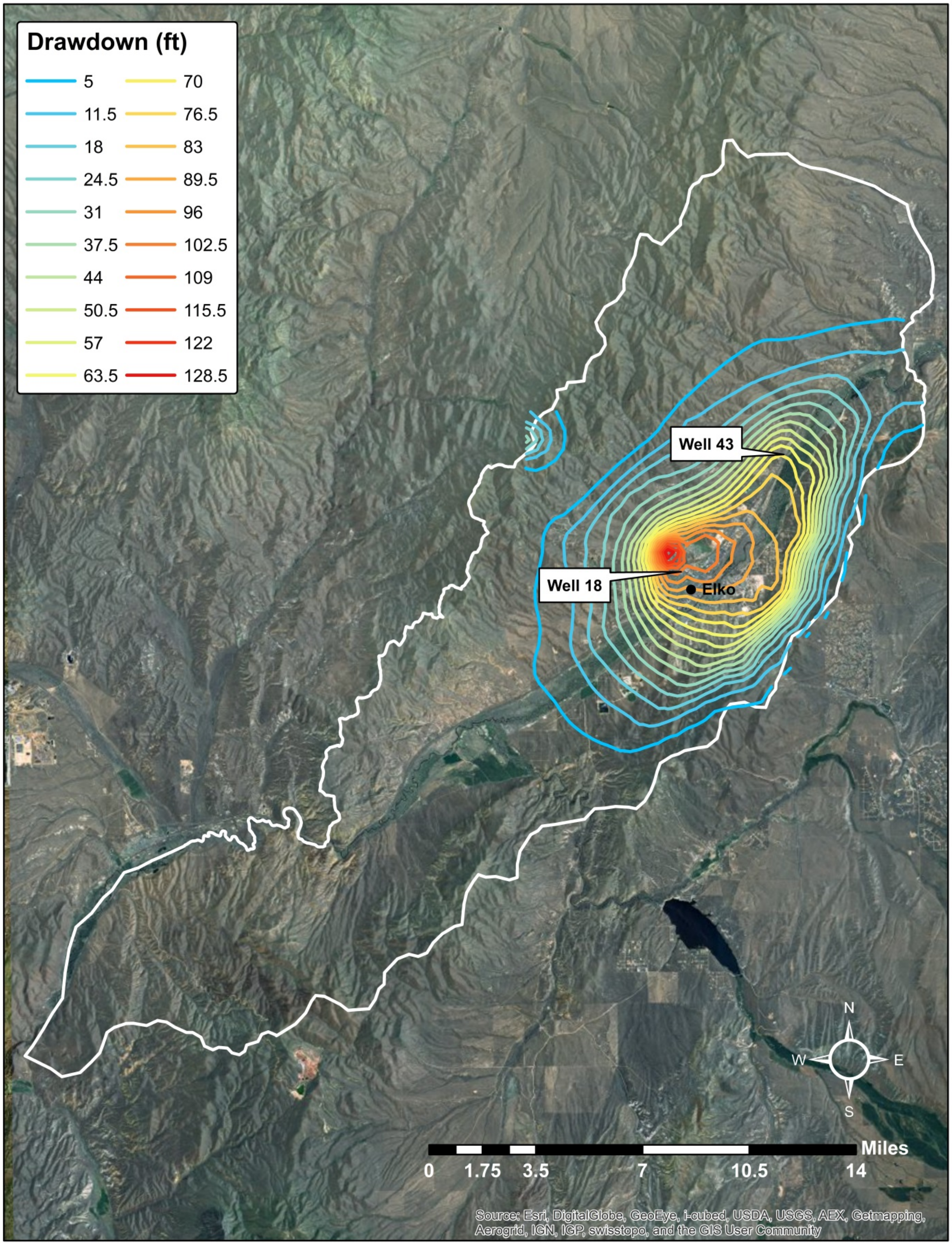

Figure 34. Drawdown in the Elko Segment after 15 years of mountain block recharge set to 100% of normal, all wells pumping at full water right.

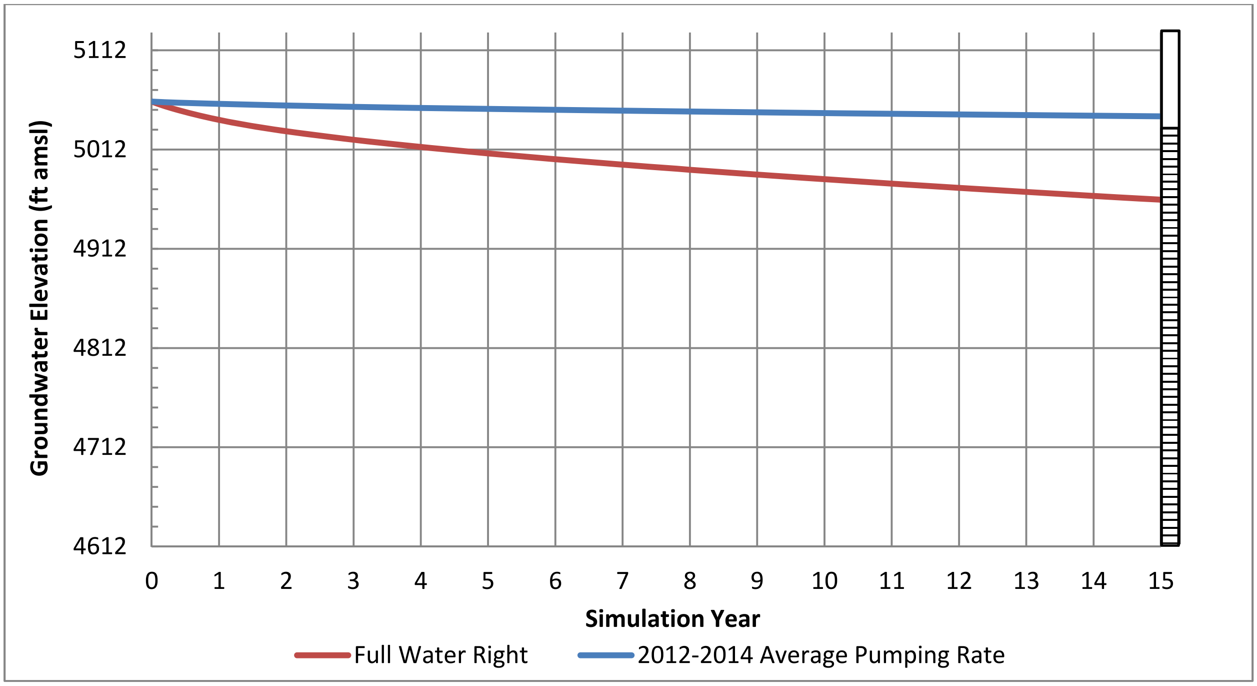

Figure 35. Declines in groundwater levels at Well 18. Total depth of well and screened interval indicated at right.

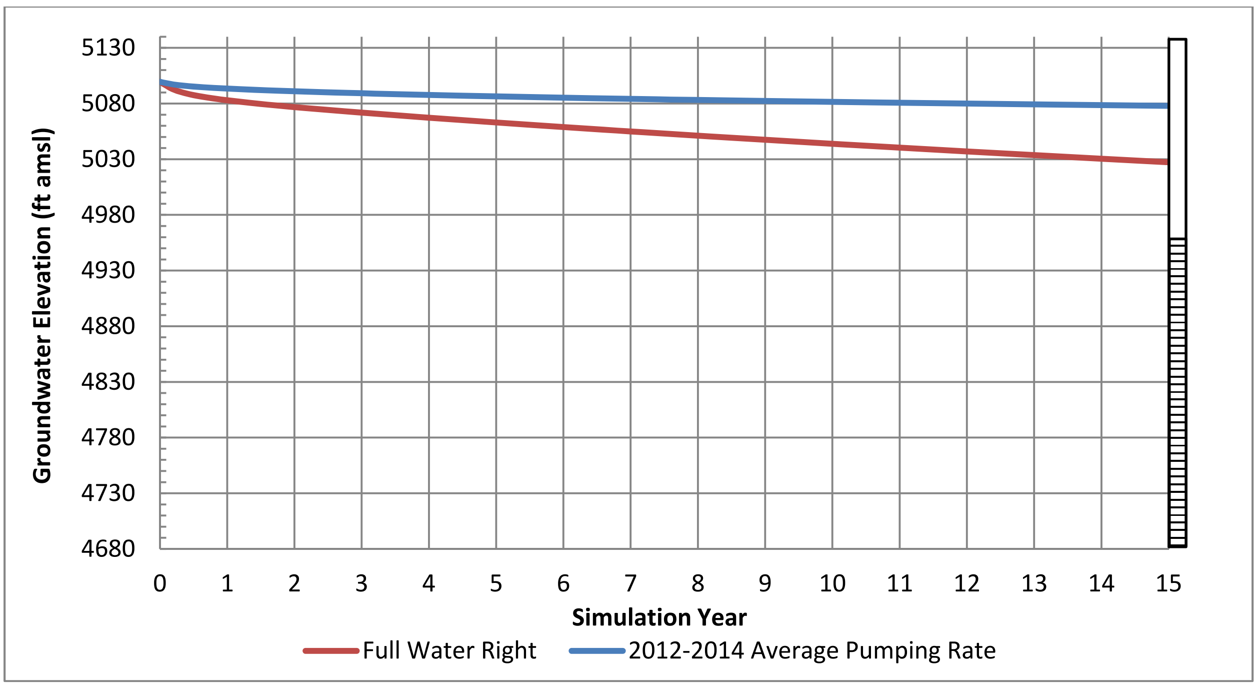

Figure 36. Declines in groundwater levels at Well 43. Total depth of well and screened interval indicated at right.

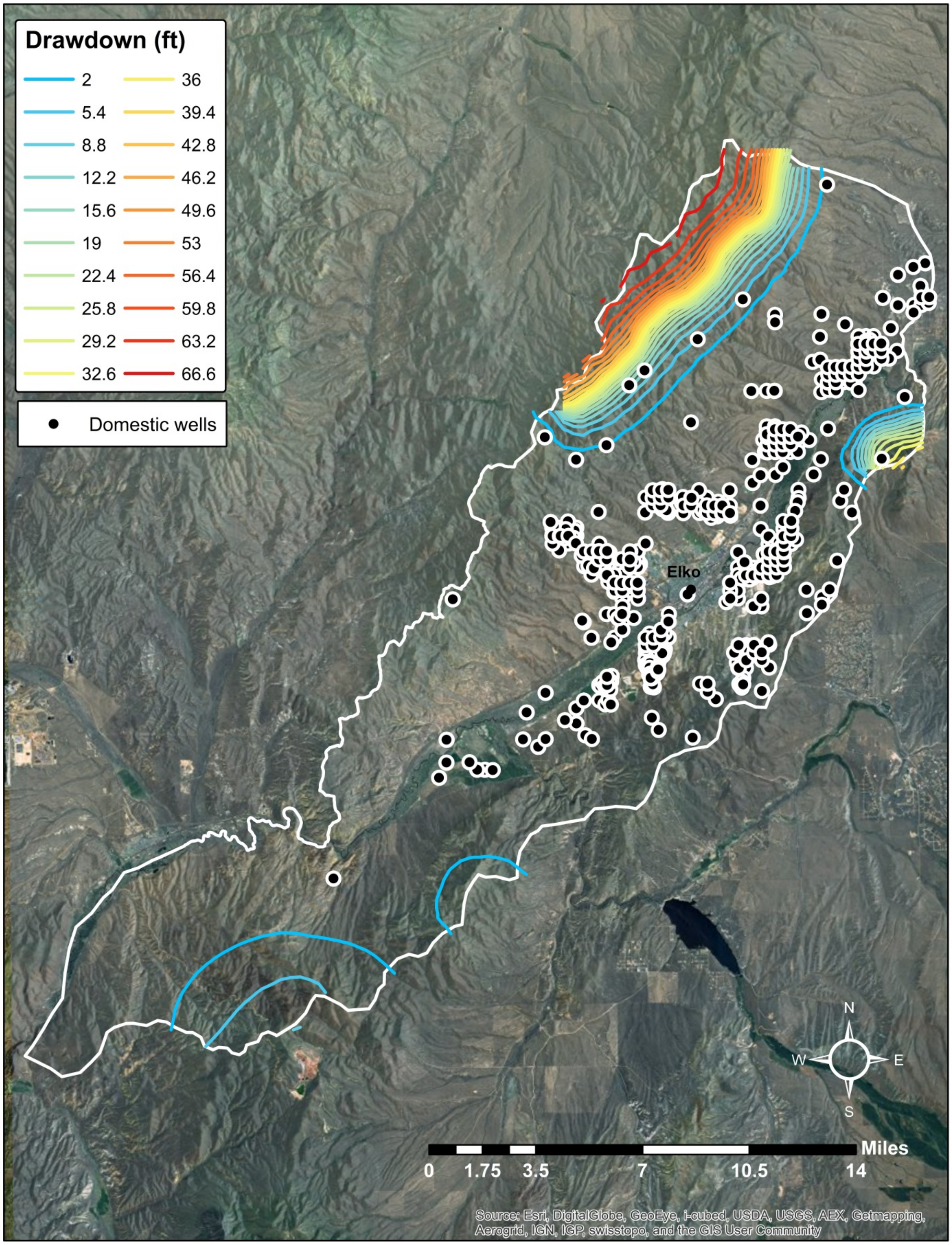

Figure 37. Difference in Elko Segment drawdown between simulation using 100% of normal recharge and simulation using 50% of normal recharge, all wells pumping at full water right.

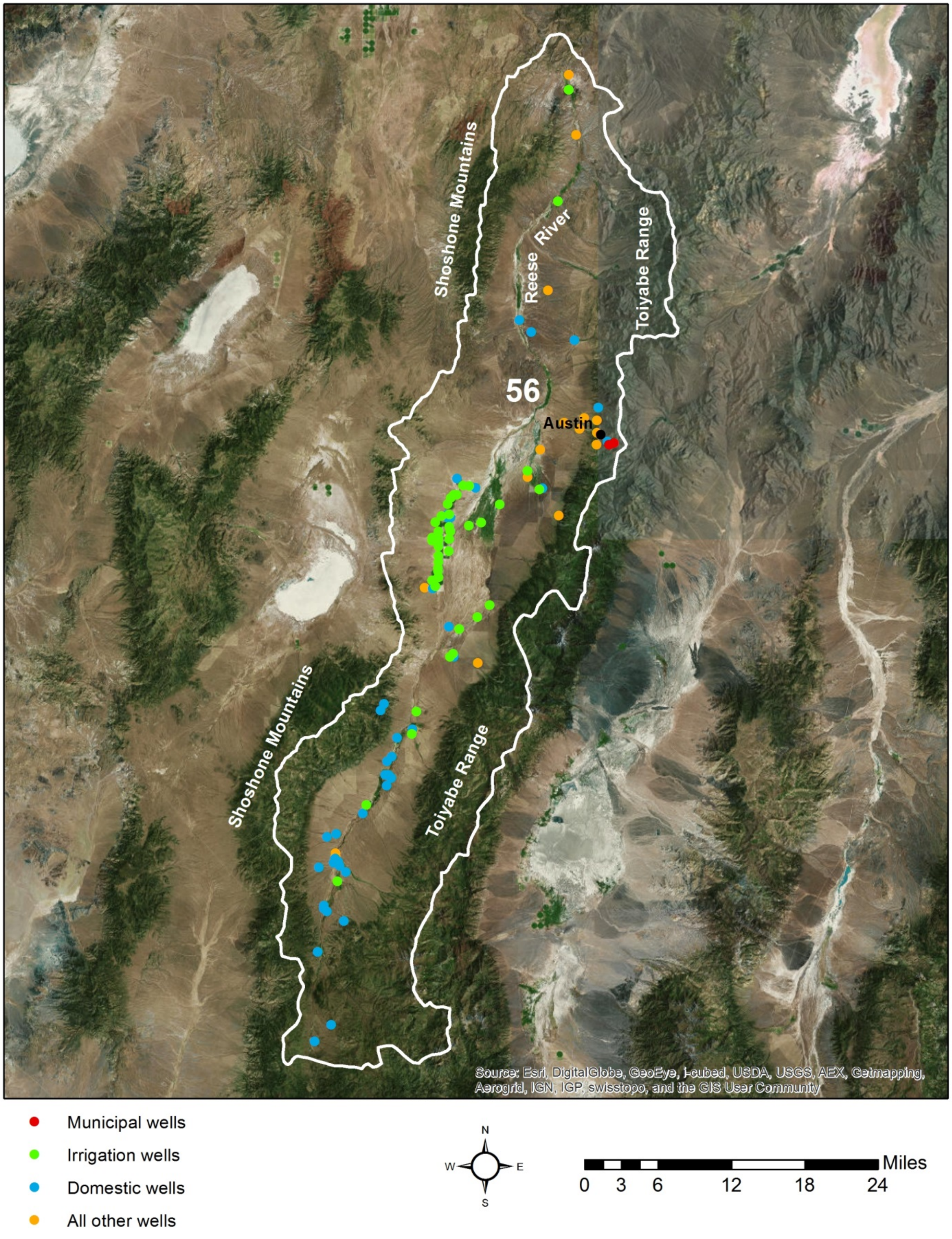

Figure 38. Upper Reese River Valley (56) and locations of wells used in transient simulations.

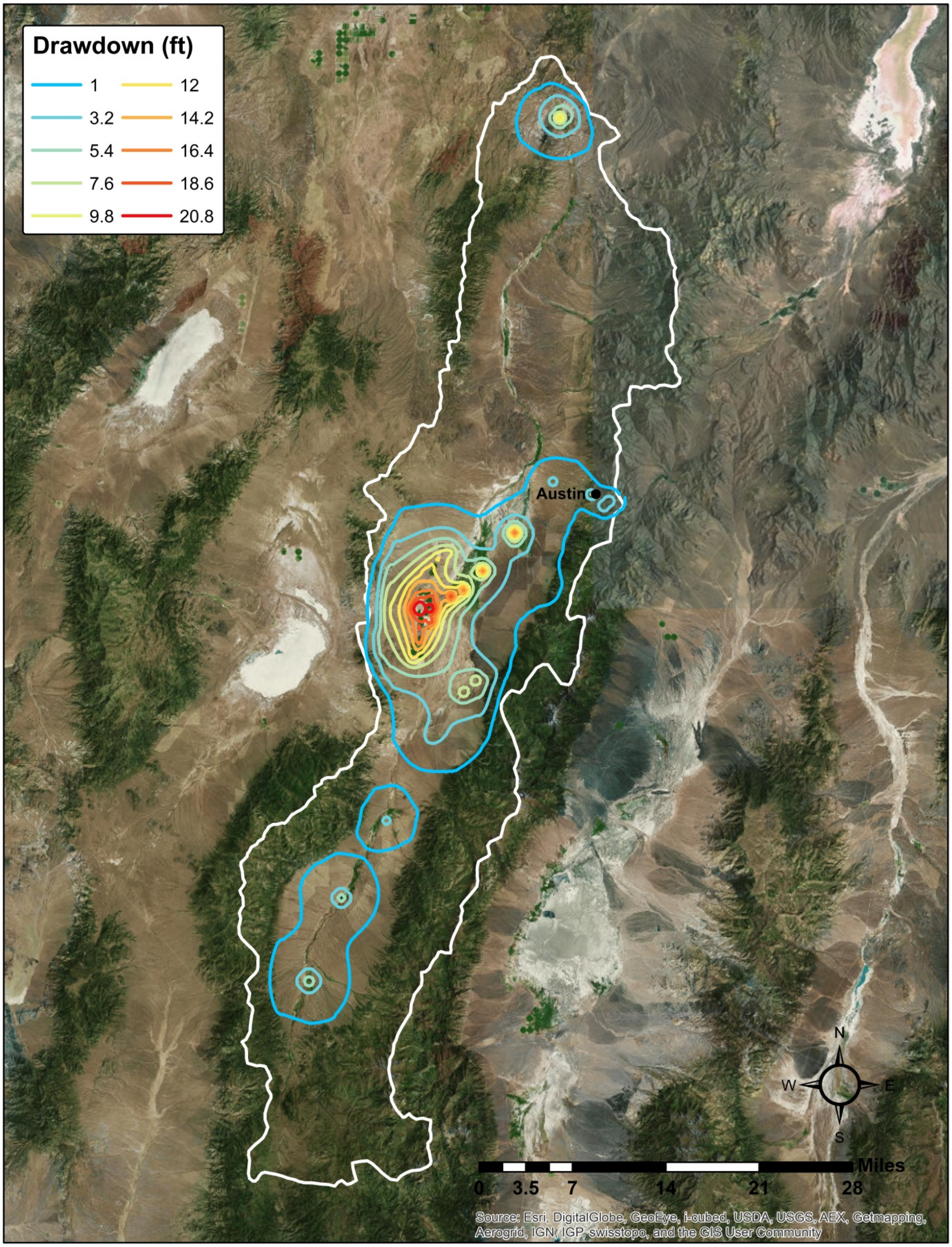

Figure 39. Drawdown in the Upper Reese River Valley after 15 years of mountain block recharge set to 100% of normal, all wells pumping at full water right.

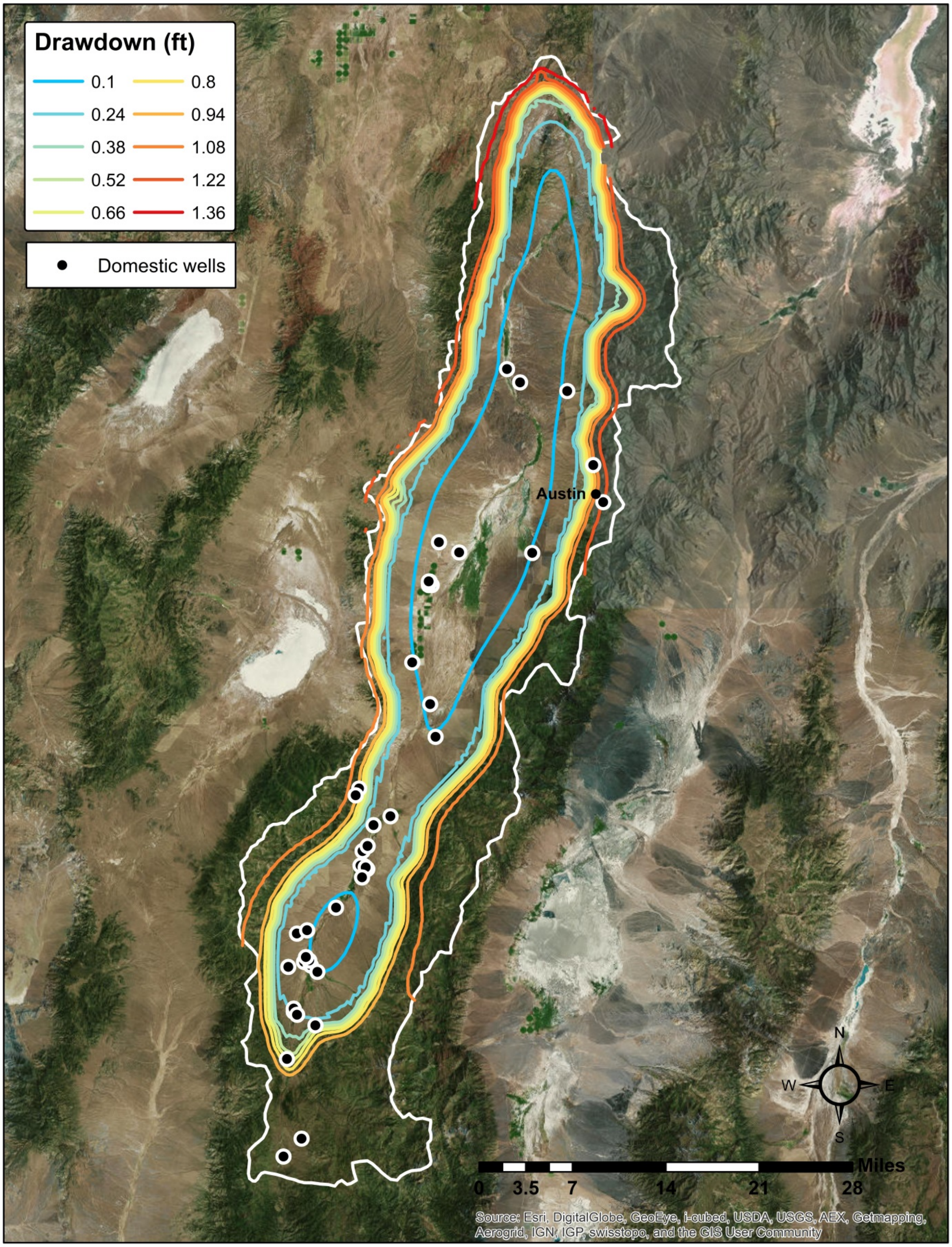

Figure 40. Difference in Upper Reese River Valley drawdown between simulation using 100% of normal recharge and simulation using 50% of normal recharge, all wells pumping at full water right.

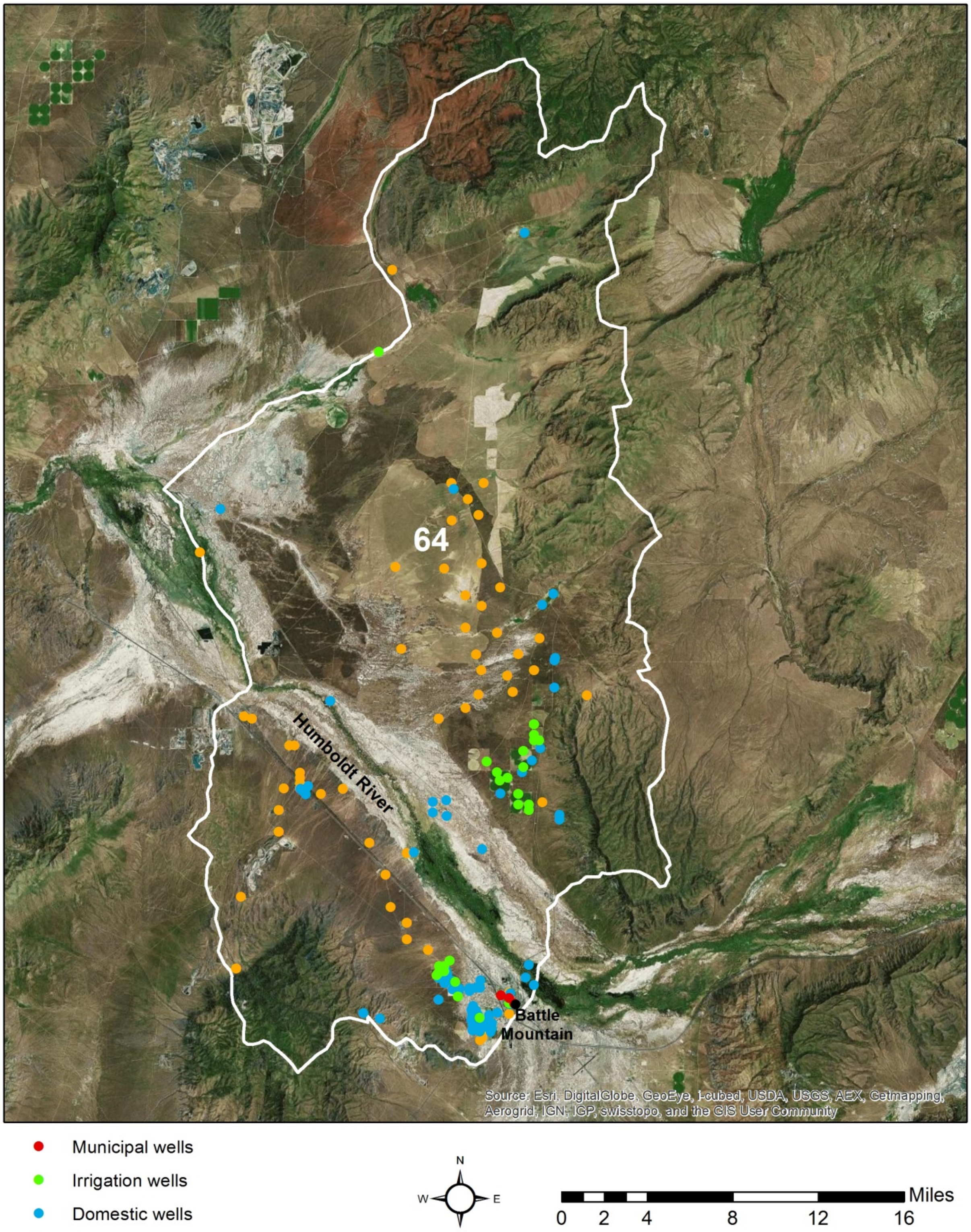

Figure 41. Clovers Area (64) and locations of wells used in transient simulations.

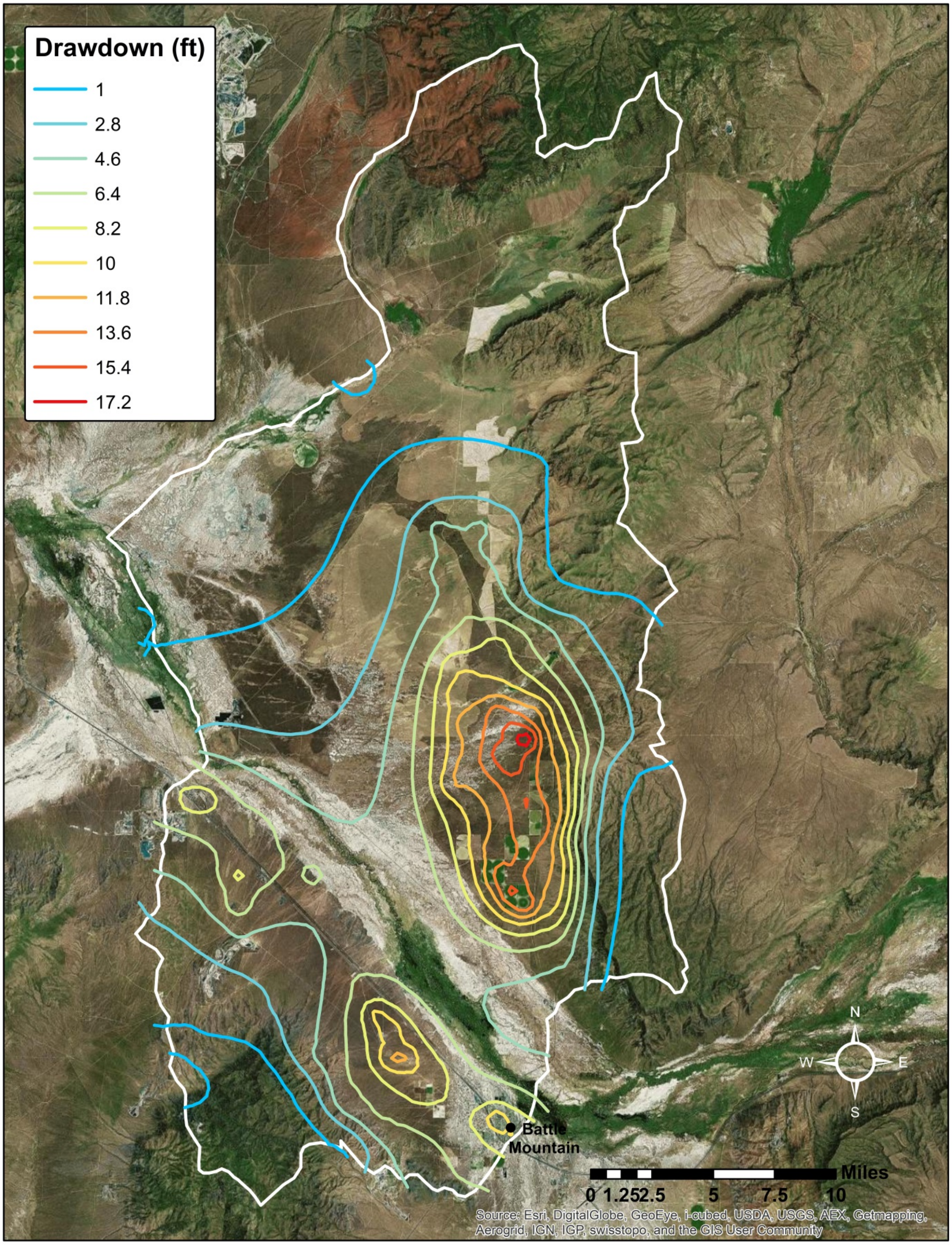

Figure 42. Drawdown in Clovers Area after 15 years of mountain block recharge set to 100% of normal, all wells pumping at full water right.

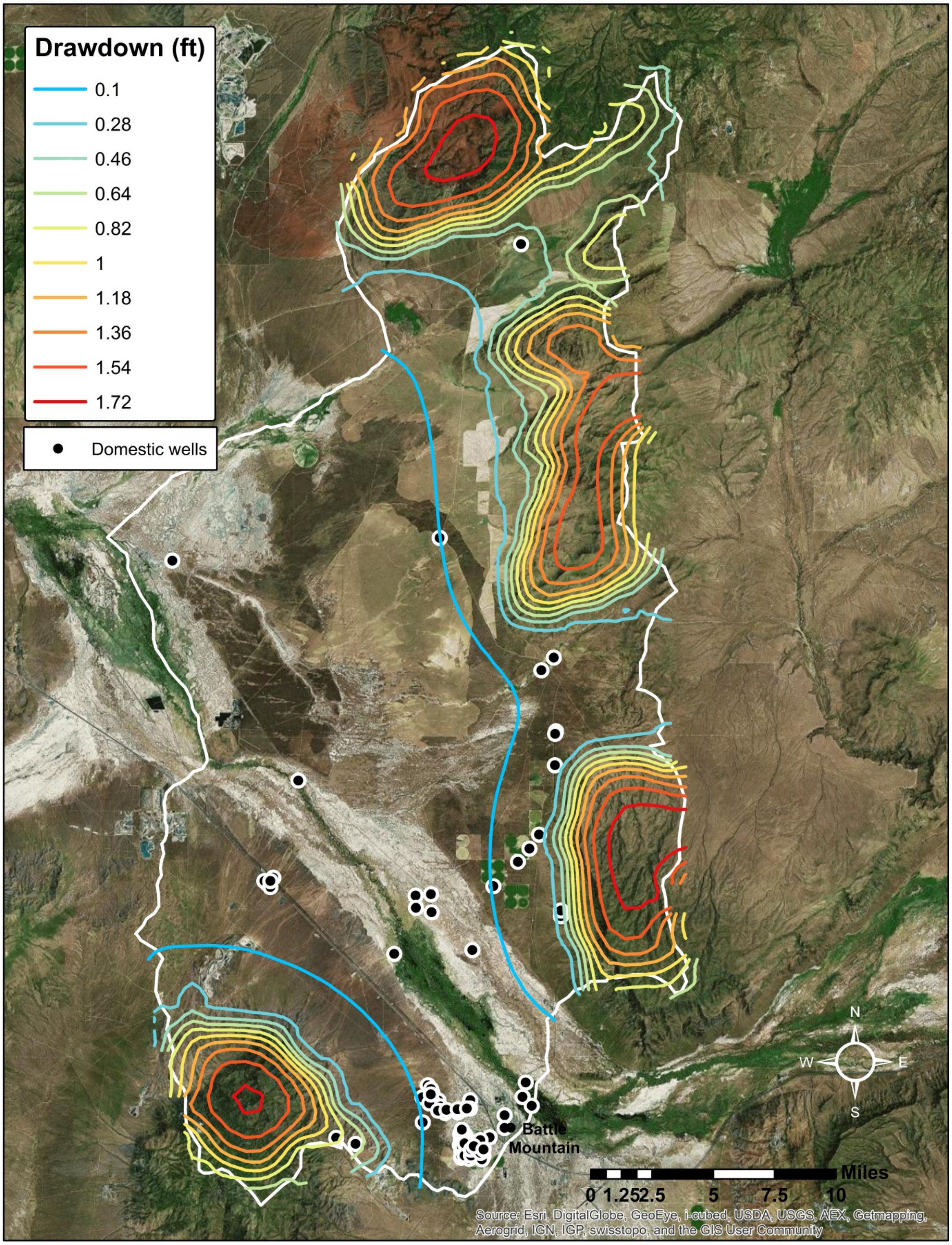

Figure 43. Difference in Clovers Area drawdown between simulation using 100% of normal recharge and simulation using 50% of normal recharge, all wells pumping at full water right.

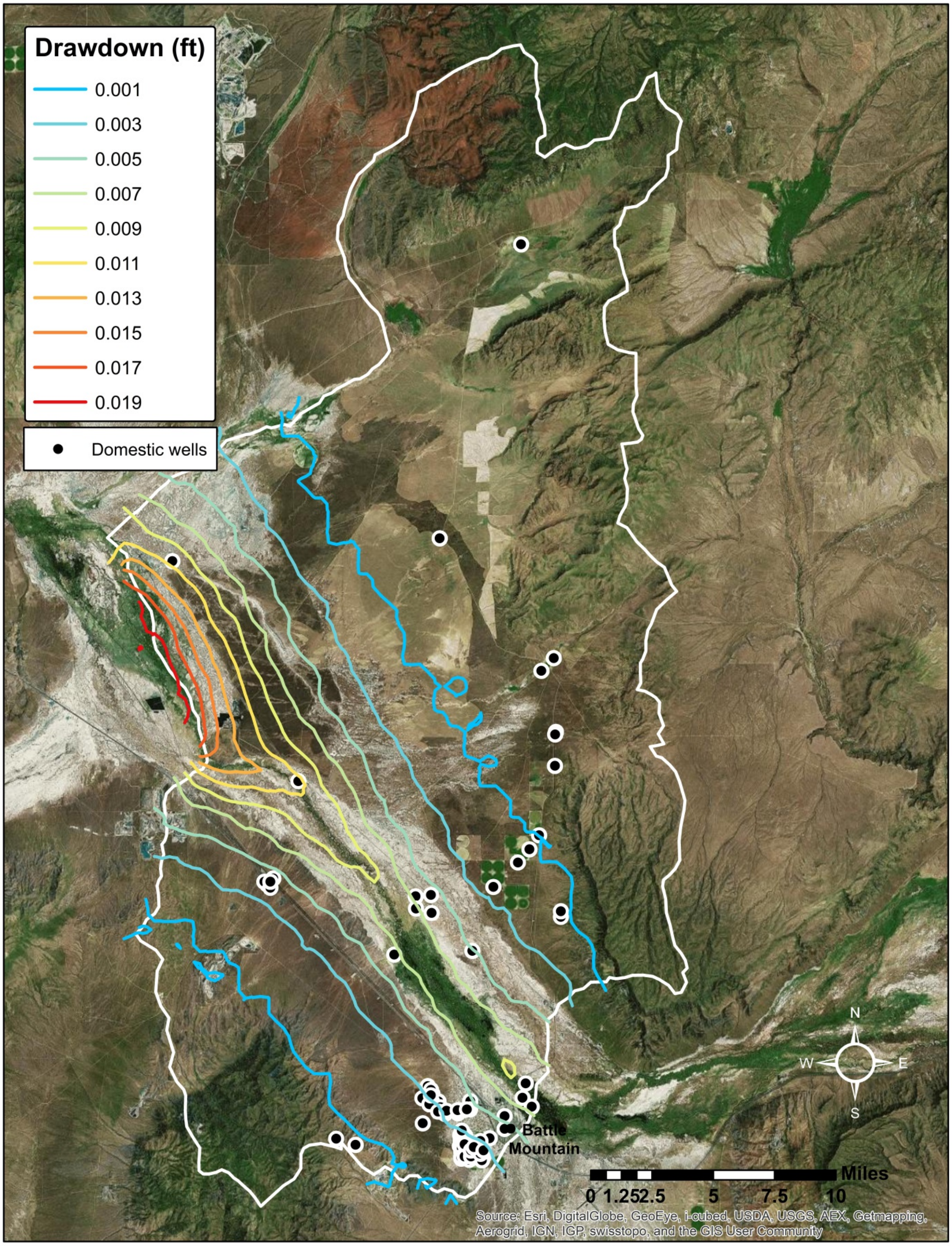

Figure 44. Difference in Clovers Area drawdown between simulation using 50% of normal recharge and simulation using 50% of normal recharge AND a 2 ft drop in river stage, all wells pumping at full water right.

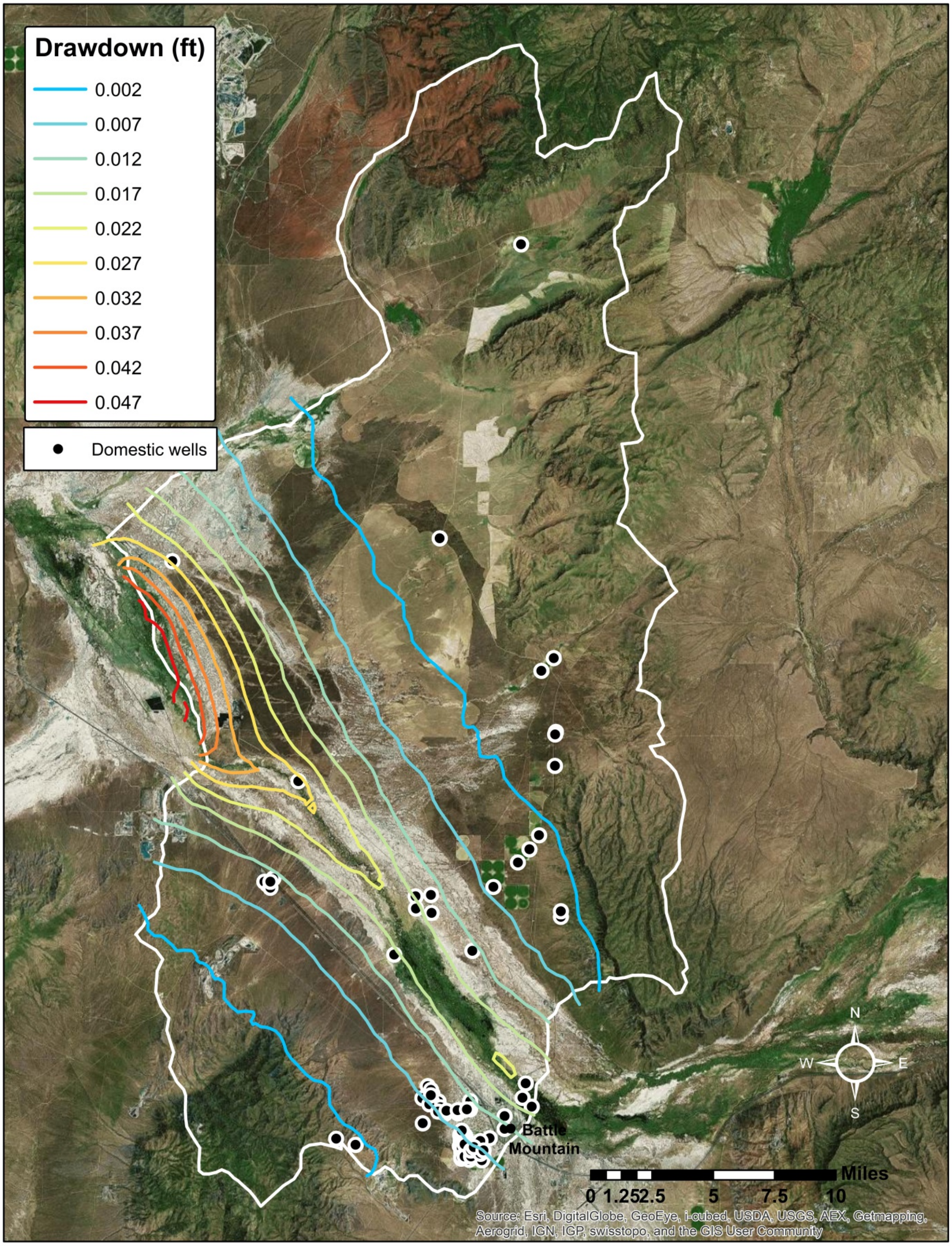

Figure 45. Difference in Clovers Area drawdown between simulation using 50% of normal recharge and simulation using 50% of normal recharge AND a 5 ft drop in river stage, all wells pumping at full water right.